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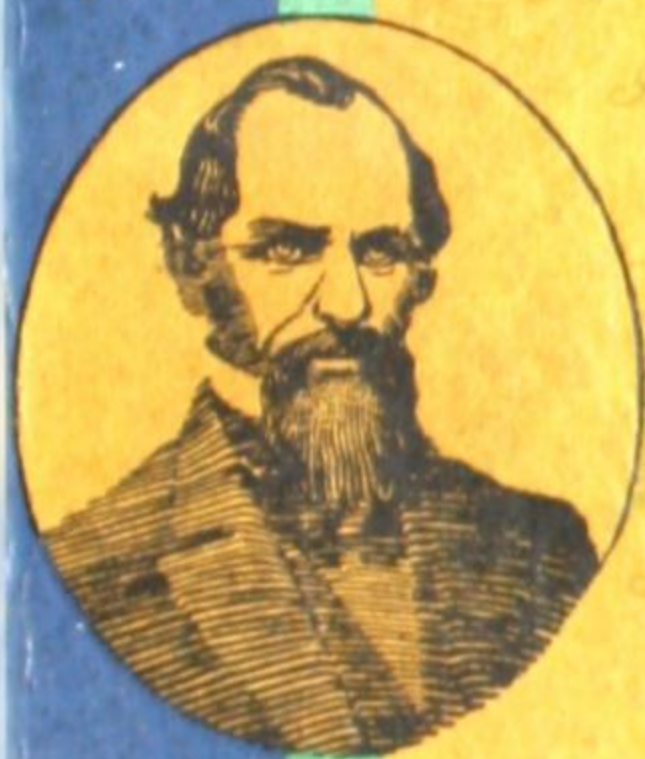
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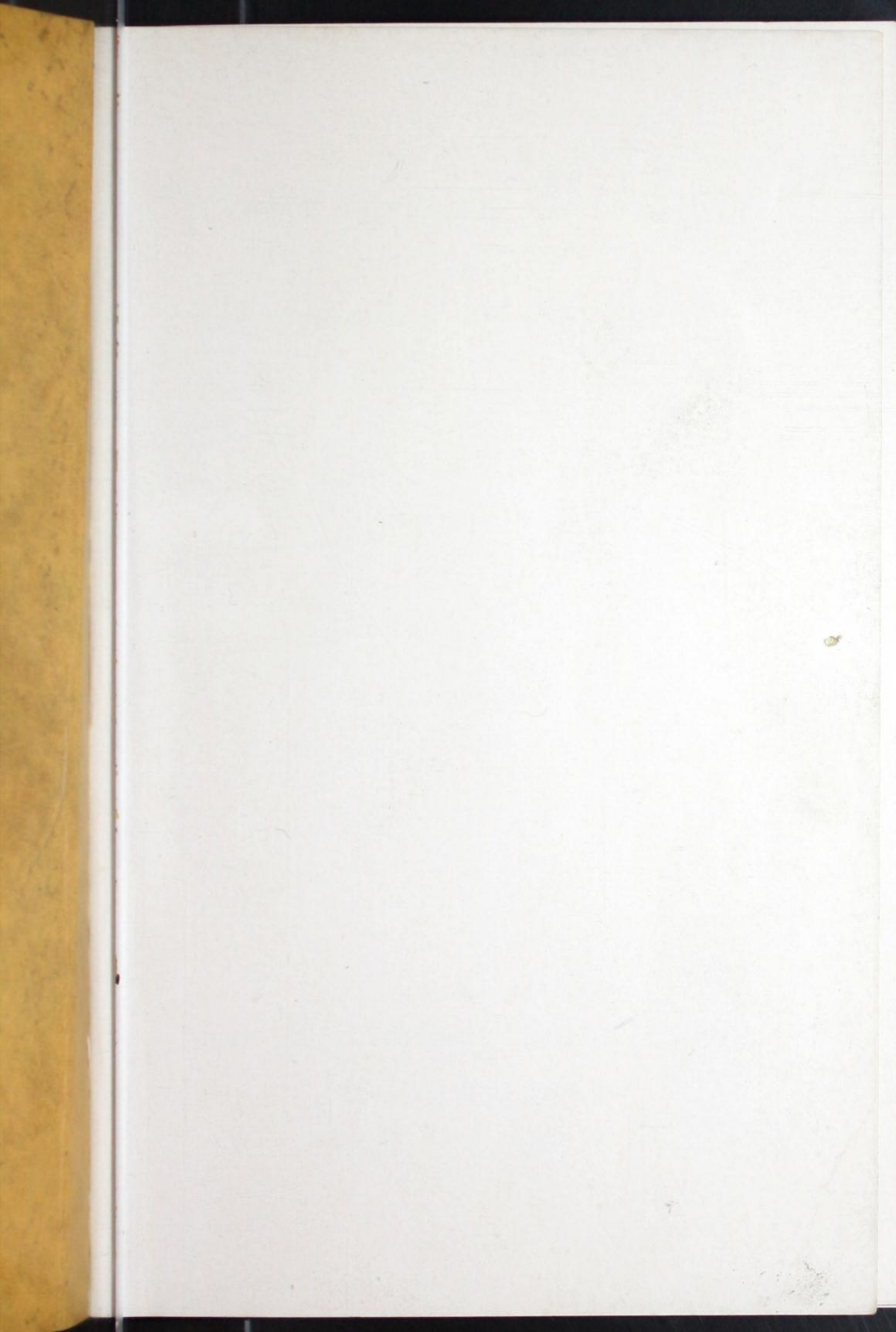
Brooklyn

Bear Mountain

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SUSPENSION BRIDGES
A CENTURY OF PROGRESS
JOHN A ROEBLING'S SONS COMPANY
TRENTON ♦ ♦ ♦ NEW JERSEY



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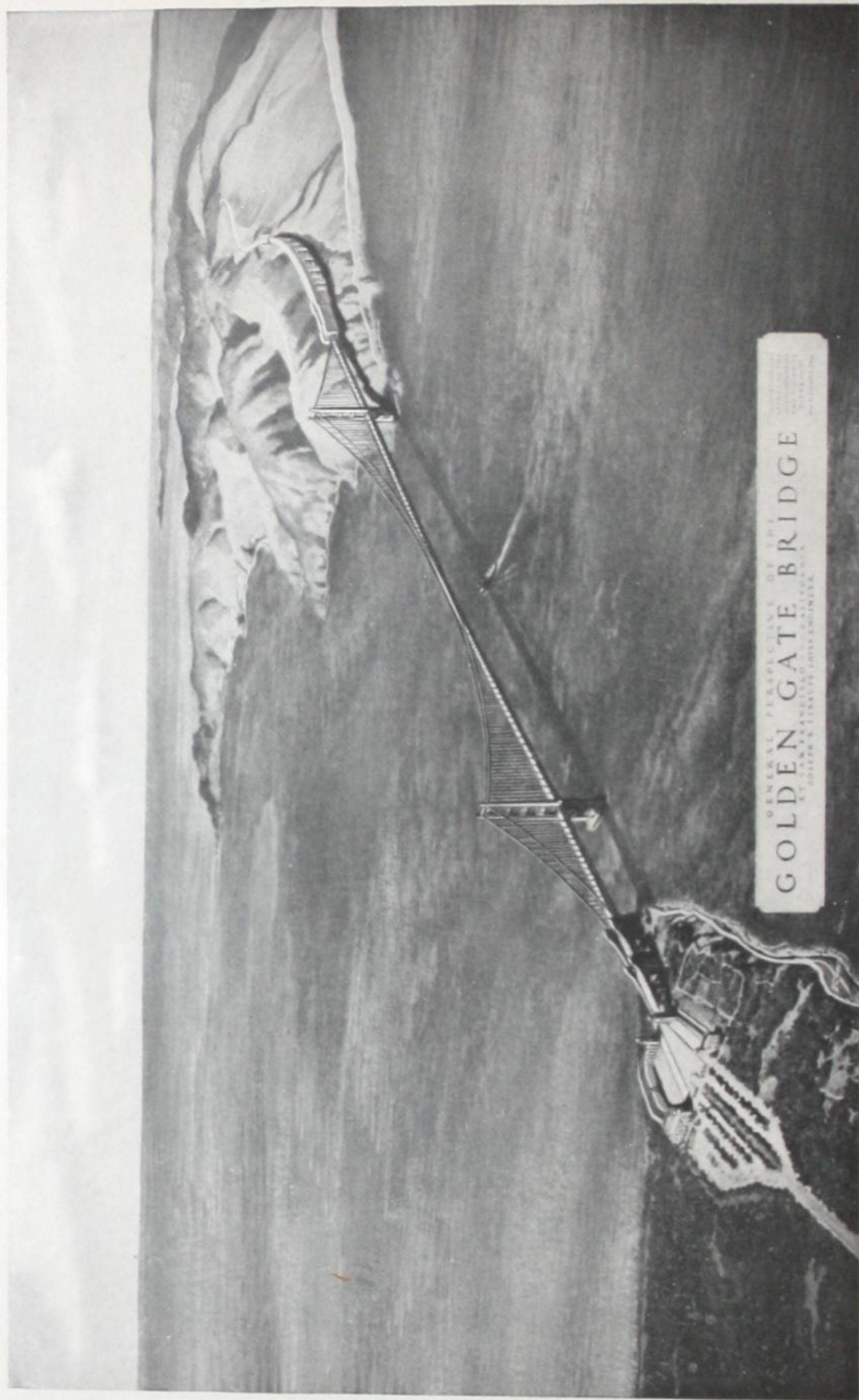
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Suspension Bridges

A Century of Progress

John A. Roebling's Sons Company

Trenton, New Jersey



COURTESY OF GOLDEN GATE BRIDGE AND HIGHWAY DISTRICT

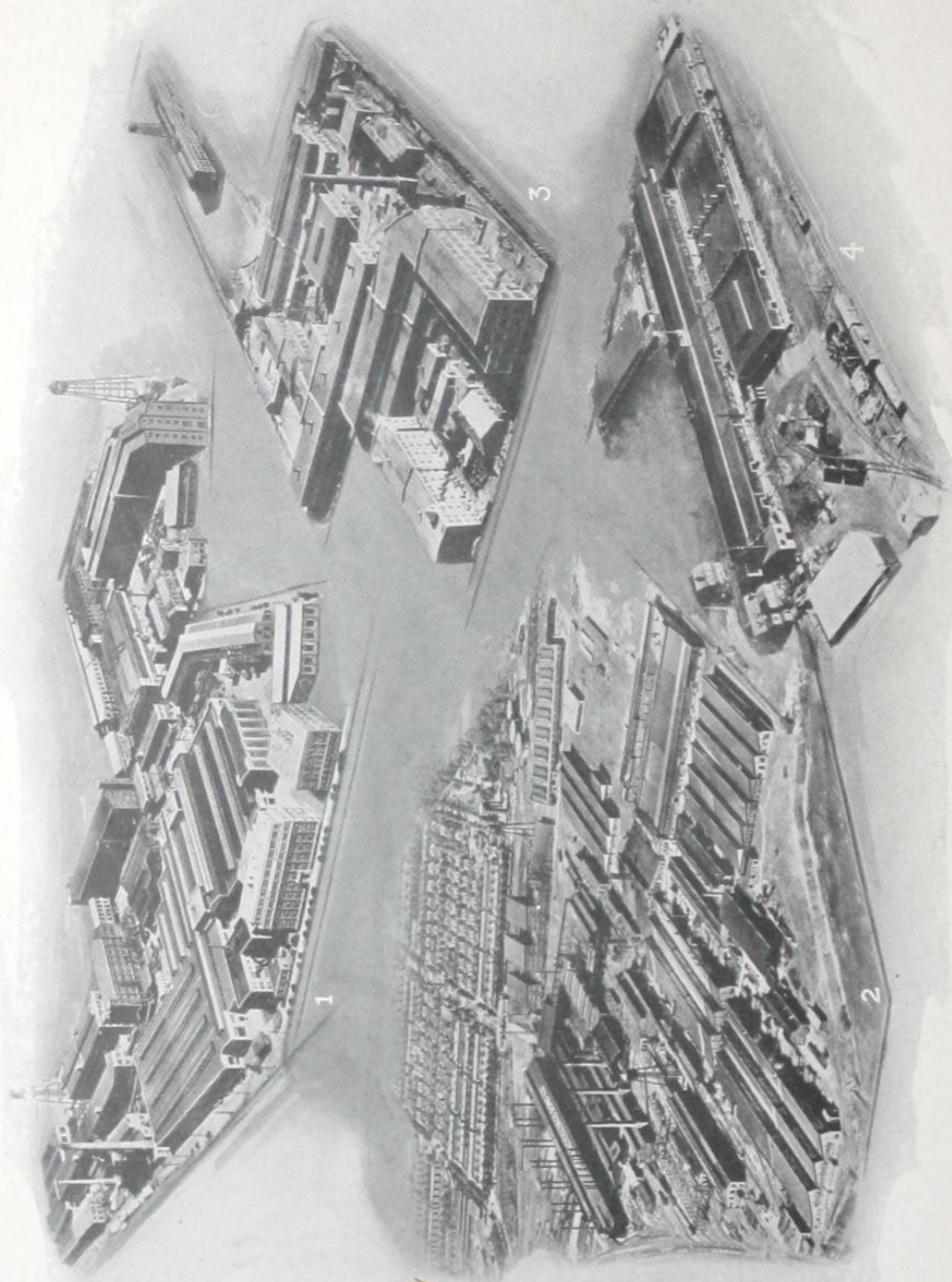
Perspective of the Suspension Bridge across the Golden Gate connecting San Francisco and Marin Counties. This bridge, which is now under construction, will have the largest and longest cables of all the world's great bridges. (See article on page 101, "How Big is a Bridge?") The cables for this great structure are being furnished and erected by John A. Roebling's Sons Company of California.

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Foreword

In publishing this pamphlet it is not the intention to offer a text book or a treatise on Suspension Bridges—this field has been well covered. Judging, however, from the number of requests we receive for information on Suspension Bridges in general, and for specific data on this or that bridge in particular, we feel that the contents may be of considerable value to the engineering profession and to all others who may be interested in this type of bridge.

Many of the articles here assembled have been published previously, notably those from THE ENGINEERING NEWS-RECORD and from WIRE ENGINEERING, by whose kind permission we are including reprints in this pamphlet.



Aerial View of the Plants of John A. Roebling's Sons Company, 1931

1—Upper Works

2—Kinkora Works

3—Lower Works

4—Electro-Galvanizing Plant

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COMPARISON OF SUSPENSION BRIDGES

Name of Bridge	Brooklyn	Williamsburg	Manhattan	Bear Mountain	Delaware River	Mid-Hudson	Mount Hope	Ambassador	George Washington	Golden Gate
Location	East River New York City	East River New York City	East River New York City	Hudson River Bear Mountain N. Y.	Delaware River Philadelphia, Pa.	Hudson River Poughkeepsie, N. Y.	Naragansett Bay Bristol, R. I.	Detroit River Detroit, Mich.	Hudson River 179th Street New York City	Golden Gate San Francisco California
Date of Erection	1870-83	1896-1903	1901-10	1923-24	1922-26	1926-30	1928-29	1927-29	1927-31	1933-
Length of Main Span in feet	1596	1600	1470	1632	1750	1500	1200	1850	3500	4200
Number of Cables	4	4	4	2	2	2	2	2	4	2
Number of Strands per Cable	19	37	37	37	61	19	7	37	61	61
Diameter of Cable in inches	15½	18¾	20¾	18	30	16¾	11	19¼	36	36½
Total No. of Parallel Wires in Main Cables	21,432	30,784	37,888	14,504	37,332	12,160	4,900	16,132	105,896	55,144
Total Weight of Wire in Main Cables in tons	3,272	4,344	6,108	1,914	6,626	1,998	700	3,097	28,500	21,500
Total Length of Cables between Anchorages in feet	3,579	2,985	3,224	2,640	3,540	3,287	2,826	3,679	5,212	7,650
Total Strength of Main Cables in tons	44,800	89,200	113,200	47,200	118,000	39,000	16,300	53,500	350,000	193,000
Diameter of Individual Bridge Wire in inches	.187	.192	.195	.195	.195	.195	.195	.195	.195	.195
Height of Towers in feet	273	310	291	350	385	315	284	363	635	746
No. and Diameter of Suspender Ropes at each Panel Point	15⅝" and 1¾"	4-1¾"	2-1¾"	2-2¼"	4-2¼"	2-17/8"	4-13/8"	4-17/8"	8-27/8"	4-27/8"

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A Short Biography of John A. Roebling

"The Father of Suspension Bridges in America"

John Augustus Roebling was born June 1806, in Mülhausen, in the state of Thüringen, Germany. Mülhausen is an old walled town founded in the year 800 and in the words of Tennyson is

"A sleepy town, where under the same wheel,

The same old rut is deepened year by year."

In those days there were no factories in Mülhausen, the mechanics and artisans doing their work in their own little houses, the whole family assisting, the women working quite as hard as the men. For more than a thousand years there had been hard work done in Mülhausen but no enterprise whatever. Hard work without enterprise is a kind of catalepsy. Life was stereotyped, society stratified.

To a man like Polycarp Roebling, father of John A. Roebling, the prescriptive life of this old German village was by no means irksome. He kept a cigar shop and managed to smoke as much tobacco as he sold. Smoking in Germany, you know, is a solace whereas in America it is an employment. To the German, smoking begets reverie and introspective philosophy. So Polycarp Roebling loved Mülhausen and lived and died there, despite his son's efforts to lure him to America.

Early Maternal Influences

The mother differed greatly from the father in character and disposition, and

John A. Roebling, was the son of his mother. She was a woman of tremendous activity, mental and physical. Deep in her soul she nourished ambitions which became tragedies through very hopelessness. And yet, weary as she was of much doing and no performance she did not whimper for sympathy. She worked for the sake of work, for the blessedness of drudgery, and confronted her disappointments with a stern Spartan courage. She had borne four children—three sons and a daughter, but it was not until her youngest child, John, had displayed mental qualities to distinguish him even in the eyes of strangers, that there dawned upon her the full significance of motherhood—its doom, its glory, its sacrifice, its triumph. Thenceforth, ambition had but one goal, life but one object—the education of her boy, through him she would achieve, through him she would fulfill her destiny. Her executive faculties developed with their exercise and she managed everything and everybody.

Thus, it was that John Roebling was enabled to graduate from the Royal University of Berlin, after a course at the Pedagogium of Erfurt, and thus it was that when shortly after he sailed to America, he carried with him a patrimony large enough to insure his establishment.

His austere, heroic mother, who had been supreme in her household, accompanied her beloved son to the port of embarkation and bade him farewell,

Height of Towers in feet	No. and Diameter of Suspender Ropes at each Panel Point	273	310	291	350	385	315	284	363	635	746
	$1\frac{5}{8}"$ and $1\frac{3}{4}"$		$4-1\frac{3}{4}"$	$2-1\frac{3}{4}"$	$2-2\frac{1}{4}"$	$4-2\frac{1}{4}"$	$2-1\frac{7}{8}"$	$4-1\frac{3}{8}"$	$4-1\frac{7}{8}"$	$8-2\frac{7}{8}"$	$4-2\frac{7}{8}"$

without a quiver of the lips or the shedding of a tear. It was an eternal farewell, for almost in the act of waving her adieux she was seized with a mortal malady and died before her son, who was destined to play so conspicuous a part in the commercial life of America and for whom her own life had been one long travail, had set foot on the promised land. Her work was completed, She had met her destiny.

A Distinguished Teacher— His Friend

At Dr. Unger's Pedagogium, in Erfurt, John Roebling won the admiring friendship of the distinguished doctor, whose numerous books on mathematics are today in the Roebling library. At the Royal University of Berlin, he studied architecture and engineering with Stüler and Rabe; bridge construction with Dietleyn; hydraulics with Eytelwein; languages in regular course and philosophy under the great Hegel, who openly avowed that John Roebling was his favorite pupil.

This last statement is important, and we repeat it. John Roebling was the favorite pupil of the immortal Hegel.

Hegel is one of the epoch-makers of the world. In the realm of pure reasoning he ranks with Plato, Descartes, Spinoza, Kant. It is impossible to study him diligently and not be profoundly influenced by his teachings, and for a youth like John Roebling to have been brought into intimate contact with this dominating personality was at once a privilege and a calamity. It was a privilege because it opened the boy's eyes to the spiritual reality back of the "change and decay" of material phenomena. It was a calamity because it begat a pride and arrogance of opinion and a frigid intellectuality that almost put the heart of him into cold storage.

In reading the biography of John Roebling we can trace the influence of

the master through the entire life of the pupil.

John A. Roebling Sails to America

John Roebling set sail for America in the year 1831, and landed on our shores a young man of twenty-five, seemingly equipped for any battle that awaited him. He was a most accomplished gentleman.

He had no knowledge of the science of farming; indeed, in his day farming scarcely ranked as a science, nor had he any practical experience in the work itself. Nevertheless he had chosen to become a farmer. He had graduated from the greatest university in the world as an architect and engineer; he was a scholar of wide reading; he was a philosopher; he was a musician; he was a master of three languages—what had all this to do with farming?

And yet he had chosen well, at least for the time being. He forthwith invested all his money in desirable land at cheap prices, thus preventing its dissipation in some visionary enterprise. And so owning good farm lands well located, he had, from the very start insured his living and independence.

The land selected by him was in the western part of Pennsylvania, Butler County, about twenty-five miles from Pittsburgh. Here he and a few of his compatriots, purchased some 7,000 acres at an average price of \$1.37 an acre, and founded the village of Germania, afterward called Saxonburg.

His biographer admits that he never became a first-class farmer. He made a living, to be sure, but it was a meagre living. He supplemented his farming with other employments and one day it occurred to him that he might patch out his income, if, between crops and during the winter, he would obtain employment as an assistant engineer in making surveys, building canals and dams for the slack-water navigation.

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His services were readily accepted, his real merits were soon recognized, and it was not long before his knowledge and skill were in active demand. Henceforth, the farm was practically abandoned, so far as John Roebling was concerned.

No doubt among our readers there are some who may recall that before the development of railroads, transportation by canal was considered the culmination of all that was luxurious and rapid in locomotion. But a canal could not cross the mountains—even Yankee ingenuity could not compel the water to run up hill. The canal boat however, was under no such limitations. It was made to cross mountains without disturbing passengers or freight, and by a very simple expedient.

The boat, you understand, was built in sections and at the base of a mountain would be separated, loaded on a portage railroad, section by section, and hauled up an inclined plane with rope and windlass. By like process it was lowered to a canal on the opposite side of the mountain, and then continued its journey.

Hemp Rope First Used on Incline

The ropes used to drag these boats over the mountains were very clumsy affairs, several inches in diameter, made of Kentucky hemp. They were very costly and short-lived and a considerable item of expense. John Roebling was of the opinion that if a rope could be made of wire flexible enough to wind on a windlass, it ought to cost little more than a hemp cable and would possess greater tensile strength with one-fourth the diameter. Moreover, it would outlast a dozen ropes made of vegetable fiber. No one in America had ever made a wire rope, nor ever seen one. Roebling himself, recalled an item in a periodical, sent him from Mülhausen, to the effect that some German inventor had produced a

wire rope, and he concluded that what an indigenous German could do in the Fatherland a transplanted German ought to do in America. At all events the idea was worth a trial. Here we note the birth of the *Roebling Idea*.

So he built a rope walk on his farm at Saxonburg, purchased a quantity of wire deemed suitable for this purpose, and actually fabricated a wire rope that surprised his most buoyant expectations. While this was a remarkable achievement, he did not stop here. The wire rope led to wire cable, still to be used in connection with canals. It seemed that canals, which are in reality artificial rivers, must sometimes cross a natural river. Here of course, the canal becomes a wooden aqueduct, but a giant aqueduct, capable of floating a flat-boat loaded to the gun'ales. In those days the building of such an aqueduct was a big and a very hazardous undertaking, for frequently the ice in the river would gorge and crush out the piers and abutments. John Roebling's inventive mind evolved an idea—another development of the *Roebling Idea*—it had its origin in a memory.

During his student days he tramped through northern Bavaria and saw for the first time, a bridge suspended by chains, spanning a small stream. He studied the structure, sketched it and made it a subject of a thesis. Now he recalled his youthful essay, and bethought him that if a cross-river aqueduct were suspended from wire cables, so much stronger than chains, it would eliminate piers and posts and other obstructions, and leave the river to flow at its own sweet will. He laid his plans and calculations before the engineers of a canal company about to cross the Allegheny River at Pittsburgh, frankly admitting that what he was proposing was without precedent. He was confident that his figures were correct and the advantage to be gained justified some risk.

He was ordered to do the work, and set about it knowing that the outcome would either place him in the forefront of American engineers, or ruin him forever. The undertaking was a success and led to many commissions for similar

Before he had completed the bridge over the Monongahela River, John A. Roebling realized that he must have shops and machinery, and possibly mills for drawing his own wire—and here the *Roebling Idea* finds further development.



High Falls Aqueduct built by Roebling in 1850. (See Page 7)

work. Several of these suspensions are still in use, unimpaired and seemingly good for all eternity.

Canal vs. Railroad

Were it not for the march of progress, with the canals being superseded by railroads, and other modes of transportation, many more of these originally constructed aqueducts would still be in operation.

The mental transition from a suspension aqueduct to a suspension bridge is a very simple process. John Roebling recognized the fact and pondered it; and the whole world knows the result of that brain action.

He also realized that Saxonburg was not a suitable location for such a plant.

Moves to Trenton

His friend, Peter Cooper, whose iron foundries were located in Trenton, New Jersey, recommended that he consider that city as a possible place for his new plant. After due investigation he purchased ground there and in 1849 moved his family. John Roebling was the architect for every building of his new plant, and the designer and inventor of nearly every piece of machinery that went into these buildings.

His continued planning and building of bridges, the erection of a bridge at

Cincinnati a
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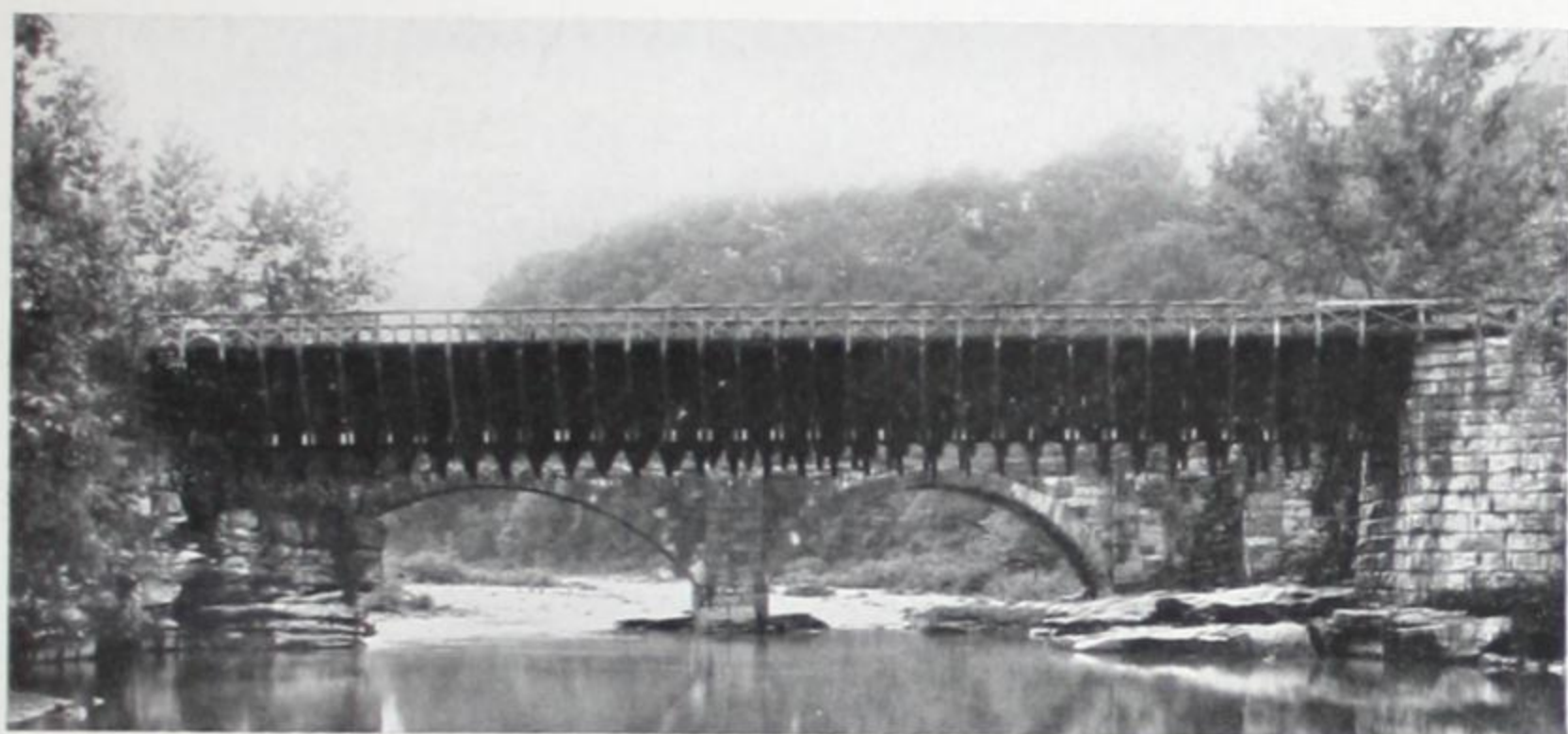


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Cincinnati and even the wonderful bridge over Niagara Falls, were only preliminary training for the monumental work which was to cost him his life, while crowning it with glory.

loose in this world!" Silas Marner, that beloved old character, the creation of George Eliots' inimitable pen, realized this force, and admitted that "though often poor ghosts, they are



High Falls Aqueduct spanning the Rondout Creek, near High Falls, N. Y.

To watch the growth of anything is always interesting, but how much more fascinating it is to retrace our steps still further into the realm of ideas and watch their development from the embryo form until they find expression in some tangible form. Ideas are the most potent factors in the history and development of this world. Socrates expressed the same thought when he said, "Beware when a thinker is let

sometimes made flesh,—and then their presence is a power, and then they shake us like a passion and then we are drawn after them with a gentle compulsion, as flame is drawn to flame."

To trace the development of the particular idea with which we are concerned—we have turned back the pages of history nearly ninety years, for the purpose of a better understanding of the *Roebling Idea*.

The Bridge Builders

Adapting the *Roebling Idea* to Suspension Bridges—

A few of the Early Bridges by the Master Suspension Bridge Builder, are here briefly sketched

YOU have been reading of the history of John A. Roebling, from his boyhood days through the early days of his development of the *Roebling Idea* and its adaption to the building of suspension bridges.

The age of wire was advancing rapidly, but John A. Roebling had set a distant mark. He believed that in wire, the solution of all of the vexing problems of bridge building, had been found. In a small way the thing was obvious but his ambition never stopped there. He believed, and had believed ever since he made the first rope, that the major part of a bridge could be made up of wires of scrupulously high quality, constructed with a rigorous regard for scientific tenets, and would carry with ease any reasonable traffic that might be imposed upon it.

Many engineers said he was visionary and a hobbyist; still with force and tenacity of purpose he urged his contentions until at last the engineering world was compelled to heed him.

In the face of such opposition, and in view of centuries that had gone by before wires were introduced in rope, it is remarkable that so soon after his initial experiment he should have worked out in practically complete detail the plan of bridge construction which came to its climax in the span of the East River—**The Brooklyn Bridge.**

The suspension bridge of the present day type is an American invention.

James Finlay, built the first regular suspension bridge in 1796 and obtained the first patent on this type of bridge from the United States government. Between 1796 and 1810, there were built 50 suspension bridges in accordance with the Finlay patent. Hand forged chains as the supporting cables were used on all of these Finlay bridges. The largest of these was the bridge across the Schuylkill River at Philadelphia with a span of 306 feet.

The most famous of these bridges is the one across the Merrimac River at Newburyport, Mass., having a span of 244 feet and was built in 1809. In 1909 one hundred years later, the Roebling Company replaced the original chains with parallel wire cables conforming to present day practice, the balance of the bridge was also rebuilt in conformity to present day practice without changing the appearance of the structure, so it retains its original outlines. One hundred years from now it will be performing its function without a question as to its strength and durability.

The Roebling Company, through its founder, John A. Roebling, was the pioneer in the construction of parallel wire cables and long-span suspension bridges. The first great achievement along this line was in 1844 when the first suspension bridge or aqueduct was constructed.

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This bridge
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The Pittsburgh Aqueduct

This bridge consisted of seven individual spans each of 162 feet in length, supported by two cables seven inches in diameter. Each cable was composed of seven strands made up of 236 wires 0.148 inches in diameter, totaling 1652 wires in each cable.

The success of this first suspension bridge was soon followed by others of greater capacity having longer spans and larger cables.

While each of these bridges has its individual history and engineering facts, (the full delineation of which would doubtless prove interesting to a large number of our readers), we shall attempt to describe briefly only a few of the most important ones, and thus sooner reach the more modern bridges which are now being built to meet even greater demands.

The Lackawaxen Aqueduct

Built in 1848 in Pike County, Pennsylvania, spanning the Lackawaxen River about two miles from its mouth. It consisted of two 120-foot spans supported by two seven-inch diameter cables, each composed of seven strands made up of 236 wires 0.148 inches in diameter, totaling 1652 wires in each complete cable.

Delaware Aqueduct

Built in 1848 spanning the Delaware River at the mouth of the Lackawaxen River. It consisted of four 134-foot spans supported by two eight-inch diameter cables composed of seven strands, each containing 306 wires 0.148 inches in diameter, totaling 2142 wires in each complete cable.

High Falls Aqueduct

Built in 1850 spanning the Rondout Creek near its junction with the Hudson River, not far from Rondout, New York. It consisted of a single 170-foot span supported by two cables nine and one-half inches in diameter, each cable

consisting of seven strands, composed of 432 wires 0.148 inches in diameter, totaling 3024 wires in each complete cable. (See illustrations on pages 4 and 5).

Neversink Aqueduct

Built in 1850 spanning the Neversink Creek three miles above Port Jarvis, having the same dimensions as the High Falls Aqueduct mentioned above.

Very shortly after John Roebling established himself in Trenton, gold was discovered in California, awakening the country to the possibilities of the West, and providing an incentive for the investment of capital in the extension of eastern railways. But rivers must be spanned to carry the rails, and transportation companies, operating lines of steamships on important rivers, rabidly opposed plans to build railway bridges with piers threatening to obstruct navigation.

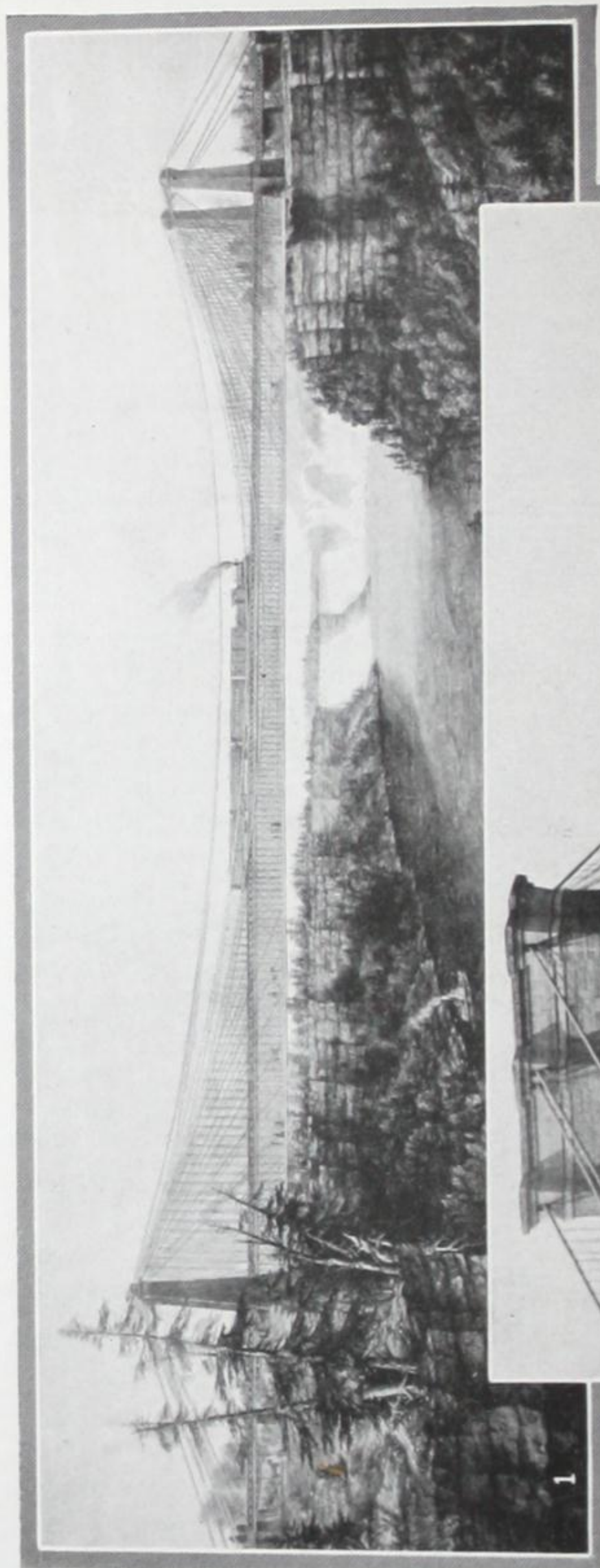
If the Niagara river could be bridged there would be no conflict with steamship lines, but the natural conditions which prevented navigation made impracticable the construction of piers in the stream. Prominent engineers who inspected the site expressed the opinion that the bridge could not be built and it seemed as though the railway must halt in its course toward the West.

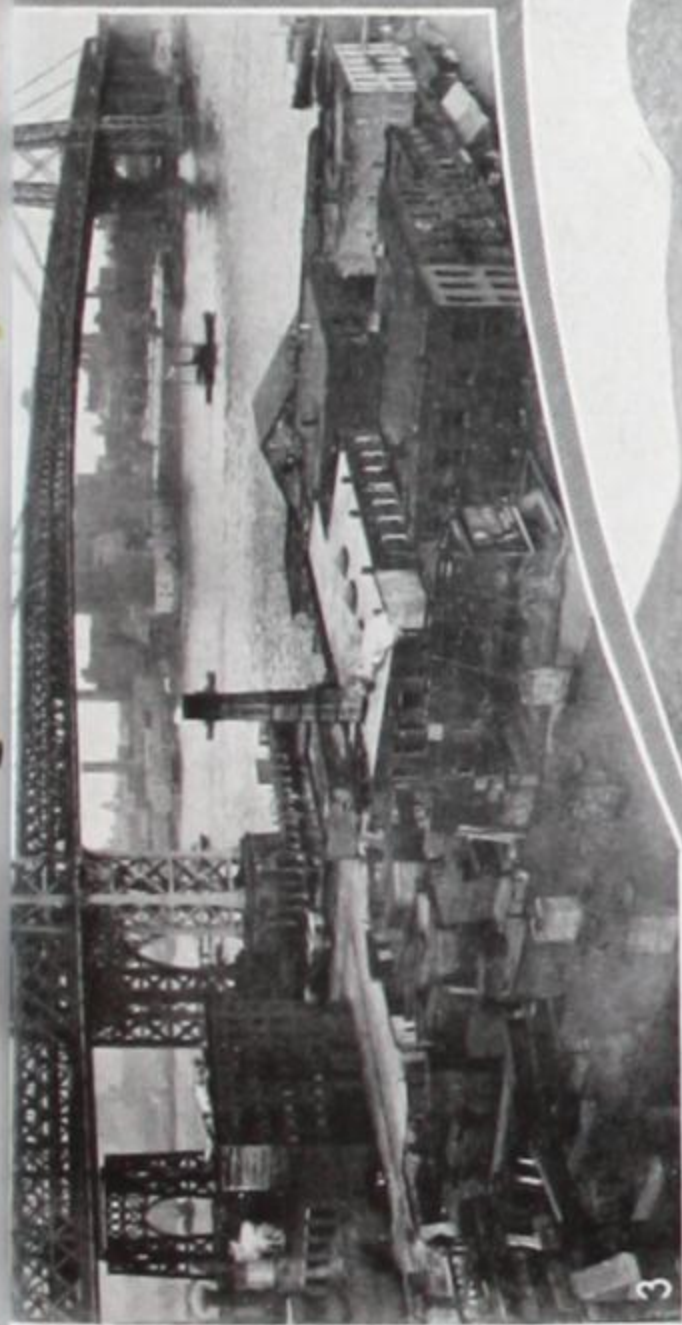
The one man of the time to present a solution of the problem was the pioneer wire rope manufacturer, whose design of suspension bridges had met with ridicule and opposition. By force of argument and logical mathematical conversation he gained converts to his belief that he could safely extend the railway across the Niagara.

Niagara Falls Bridge

In 1854 there was accomplished the apparently impossible feat of constructing a combination railroad and highway suspension bridge across the Niagara Falls rapids. This bridge consisted of an 821-foot clear span between

A GROUP OF EPOCH-MAKING BRIDGES





- | | | |
|--------------------------------|-------------------------------|--------------------------------|
| 1. Niagara Falls Bridge (1854) | 3. Williamsburg Bridge (1903) | 4. Manhattan Bridge (1909) |
| 2. Brooklyn Bridge (1883) | | 5. Bear Mountain Bridge (1924) |

towers, supported from four cables ten inches in diameter, each cable consisting of seven strands, each strand com-

posed of 520 wires 0.148 inches in diameter, making a total of 3640 wires in each cable.



The Allegheny Bridge built in 1856

posed of 520 wires 0.148 inches in diameter, making a total of 3640 wires in each cable.

Allegheny Bridge

Built in 1856 across the Allegheny River, at Pittsburgh, having two spans of 344 feet each. This bridge was supported by four cables—two cables seven inches in diameter and two cables four inches in diameter, made up of wires 0.148 inches in diameter.

Cincinnati Bridge

Opened to traffic January 1, 1867, crossing the Ohio River between Cincinnati, Ohio, and Covington, Kentucky. This bridge was another great undertaking of the Roebling Company. It has a clear span of 1057 feet, which

was the longest in existence at that time. It was supported by two cables, each having a diameter of twelve and one-third inches and composed of 19 strands, each strand containing 274 wires 0.148 inches in diameter, making a total of 5206 wires in each complete cable. The suspended length of each of these cables is 1700 feet between center line of anchorage pins. In 1896 and 1897, in order to accommodate greatly increased traffic conditions, this bridge was reinforced by two additional parallel wire cables, each ten inches in diameter and composed of seven strands of 520 wires 0.148 inches in diameter, totaling 3640 wires in each of the new cables. These cables were supported upon separate saddles directly over the old cables, and the proportionate loading was transferred to the new cables by means of special readjustment of the suspender ropes.

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Early in the accomplishment talk of two construction under seas emphasize the A. Roebling, bridge idea, a connect New York a suspension people of Brooklyn which they had pretense of enjoying The crust of c indurated with Brooklyn residents River in profit boats too long any liaison with by way of a w

Roebling was he hustled v Brooklynites uncertain way of storm and gave them s ferryboats sti vicious winter terest, longest wrung forth They could w the weather, could turn th was grand a cates of th traveling by t reached New man who dic and left his same hour.

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Epoch-Making Bridges

The Brooklyn Bridge

Early in the fifties, when the Niagara accomplishment was more or less the talk of two continents and communication under seas by cable had helped to emphasize the possibilities of wire, John A. Roebling, protagonist of the wire bridge idea, advanced a proposal to connect New York and Long Island by a suspension bridge and release the people of Brooklyn from a segregation which they had made a somewhat futile pretense of enjoying. Habit dies hard. The crust of custom becomes strangely indurated with long exposure, and Brooklyn residents had fought the East River in profitable, if archaic, ferryboats too long to be lured lightly into any liaison with iconoclastic Manhattan by way of a wire bridge.

Roebling waited another decade, but he hustled while he waited. The Brooklynites continued to make their uncertain ways across the river in times of storm and tide and ice as the Lord gave them strength, and the sacred ferryboats still paid dividends. The vicious winter of 1866-7, coldest, bitterest, longest the cities had ever known, wrung forth at last a cry for relief. They could wrap themselves up against the weather, but no weight of woollens could turn the shafts of ridicule. It was grand ammunition for the advocates of the bridge, when people traveling by train from Albany actually reached New York sooner than did the man who did business in New York, and left his home in Brooklyn at the same hour.

And besides, the Roebling cap had another feather in it now, in the completion of the Ohio Bridge. He was building wire bridges everywhere, and it began to look as though there was

some body of truth in the Western contention that New York was the most provincial city in America, for all its self-approval.

At one of the many hearings that were held on the bridge question, a famous engineer who favored the wire type, was asked what reason he had for believing it would do the work. "I believe it," he replied, "because Roebling says so."

The Initial Charter Granted

The demand for the bridge rose to a clamor. In the month of May, 1867, the initial charter was granted, and John A. Roebling was appointed engineer. Three months afterwards he submitted his report and estimates, which were examined and approved by a commission of engineers in the United States War Department. Then he set about preparation for the task.

The Death of John A. Roebling

It was while fixing the location for the Brooklyn tower that he met with the accident that caused his death. But his work had been well done, and his son and associate, Col. Washington A. Roebling, took up without delay the execution of the plan he had helped to create.

If the older Roebling encountered obstacles in bringing his great idea to the point of acceptance, the pathway of his successor, called without warning to take over the responsibility for the greatest engineering labor of the age, was not strewn with roses.

Work of Construction Begins

It was in the summer of 1869 that John A. Roebling died. The second day of January, 1870, saw the actual

work of construction begun, when laborers started to clear away to prepare for the foundations of the Brooklyn tower. From that day forward, through a baker's dozen of years, there was no rest, though there was plenty of interruption. Until the job was ended Washington A. Roebling simply lived the Brooklyn Bridge. It was a colossal job, punctuated with changes and problems and complications, but it went forward. The landmarks of a bygone age, old houses of historic memory on the water fronts of both cities, vanished silently and where they had been by and by there grew piles of masonry to form the approaches.

From the huge caissons over against either shore rose the towers, tall and grim, which were to carry the cables. In due time they stood complete, with their broad bases welded to the rock by an ingenious bond of stone and concrete in the river's bed, and their crests nearly three hundred feet above the top of the tide. A hundred and nineteen feet—and three inches, to be precise—above the water opened the two tall arches in each tower, stretching upward one hundred and seventeen feet in the air. It was through these the bridge proper was to pass, with its gangways for horse and foot and railway traffic.

Could Those Slender Towers Carry The Great Load?

The hurrying people of New York and Brooklyn watched the thing grow and wondered fearfully whether the slender towers would stand the strain. In Harper's Magazine for May, 1883, now itself yellowed by age, is an exhaustive article concerning the Brooklyn Bridge, in which one is told at length and with engineer's exactness, the steps by which the achievement, after thirteen laborious years, was brought to proud completion.

Should we attempt to tell the whole story of the now famous Brooklyn Bridge, it would be keenly interesting, and indeed would read like a romance and would hold your interest throughout; but we need to confine ourselves at this time, to a few of the facts which are also very interesting in these days of super spans.

The Brooklyn Bridge

The completion of this famous structure, opened to traffic in 1883, marked the greatest advance in suspension bridge construction up to this time.

The bridge has a main span of 1595.5 feet, and is supported by four cables each having a diameter of fifteen and one-half inches. The cables consist of 19 strands, each composed of 282 steel wires 0.187 inches in diameter, after galvanizing, totaling 5,358 wires in each cable.

The cables have an ultimate strength of approximately 11,200 tons each, and if the total amount of wires in all four cables was stretched in one continuous length, it would cover a distance of 14,568 miles.

The three most important differences between the Brooklyn Bridge and other suspension bridges built previously are;

1st—Great increase in cable length. Including both side spans this bridge has a total length of 3455.5 feet suspended from the cables. The total length of each of the cables between center lines of anchorage pins is 3578.5 feet, making them the longest parallel wire cables ever fabricated for a suspension bridge.

2nd—The Brooklyn Bridge marked the first use of steel as a material for bridge wire. All previous suspension bridge cables were fabricated from wire drawn from charcoal iron.

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pendent upon oil, grease, and paint for protection against the elements. In the Brooklyn Bridge, however, the cables were fabricated from galvanized wire, thus bringing into use for the first time, zinc as a protective coating for suspension bridge cable wire.

Williamsburg Bridge

This bridge, completed in 1903, has a main span of 1600 feet between towers, and is supported from four cables, eighteen and three-quarters inches in diameter, each consisting of 37 strands, and each strand composed of 208 wires 0.192 inches in diameter, totaling 7696 wires in each cable. The suspended length of each cable is 2985 feet between center lines of anchorage pins, and the four cables contain a total wire length of 17,432 miles. The ultimate strength of each of these cables is approximately 22,300 tons.

Manhattan Bridge

The Manhattan Bridge, the latest of the New York City Suspension Bridges, was opened to traffic in 1909 and has a main span of 1470 feet, supported from four cables twenty and three-quarters inches in diameter, and consists of 37 strands. Each strand is composed of 256 galvanized wires 0.195 inches in diameter, making a total of 9472 wires in each cable. The total length of each of these cables is 3224 feet between center lines of anchorage pins. The continuous wire length of the four cables totals 23,170 miles, and the ultimate strength of each of these cables is approximately 28,300 tons.

Parkersburg Bridge

This bridge was built in 1916 across the Ohio River at Parkersburg, West Virginia, and consists of three spans of 275 feet, 775 feet, and 375 feet respec-

tively. The bridge is supported by two cables each eight and one-quarter inches in diameter, composed of seven strands each having 280 galvanized wires 0.165 inches in diameter, totaling 1960 wires in each cable.

Rondout Creek Bridge

This bridge, spanning the Rondout Creek at Kingston, New York, was opened to traffic in 1922, and is one of the more recent bridges supported by cables of Roebling wire. It has a main span of 705 feet and is supported by two cables nine inches in diameter, consisting of seven strands, each composed of 282 galvanized wires 0.195 inches in diameter, totaling 1974 wires in each cable. Due to the steepness of the backstays, it was necessary to add two extra strands from each tower to the anchorages, these strands consisting of 76 wires, so that each of the backstay cables contained a total of 2126 wires. The total length of wire in both of these cables equals 936 miles, and the strength of each cable approximates 6320 tons for the main span, and 6803 tons for the side spans.

Bear Mountain Bridge

The Bear Mountain-Hudson River Bridge was dedicated and opened to the public on November 26, 1924, thus completing, after record progress for this type of construction, one of the longest span bridges in the world devoted entirely to highway traffic. The opening of this bridge provided a greatly needed short route for East and West-bound traffic between New Jersey, Pennsylvania and New York, on the western side of the river, and the New England States on the Eastern side, as well as within the Empire State itself.

Nomenclature of Wire Bridge Cables

THE Suspension Bridge Cable made up of parallel, multiple, prestressed bridge strands; is widely accepted as the most economical and satisfactory type developed to date for intermediate span bridges. The innovation of prestressing was first introduced in 1928 in connection with the foot-bridge cables of the George Washington Bridge. Since that time five bridges, ranging in main span from 800 ft. to 1207 ft., have been built; and four additional bridges with spans of from 700 ft. to 1280 ft. are either building or projected, all using this type of main cable.

In spite of the fact that such cables are rapidly gaining in favor, it seems when referring to them that there are a number of different terms in use. To many they are "Rope Strand Cables"; to others they are "Twisted Strand Cables"; to us they have been "Prestressed Bridge Strand Cables"; and so on. Unless some proper designation is accepted and adopted, the result might well lead to confusion.

The term "Parallel Wire Cable" is most descriptive of a cable type and is recognized by the engineering profession at large. It describes the cable exactly: "A cable made up of a number of wires each of which is parallel to the other." But what does "Rope Strand Cable" bring to mind? What does the word "Rope" signify? Is the strand twisted

into a rope or was it made as a rope strand? How are the strands laid into the cable? The term leaves us completely up in the air and is therefore far from descriptive.

The name "Twisted Strand Cable" is no more satisfactory. Are the strands twisted? No, they are laid parallel. Then why "Twisted Strand?"

"Prestressed Bridge Strand Cable" is more to the point, but it is still far from satisfactory.

There are, in reality, only three types of wire suspension bridge cables (we do not include cables of one strand or one rope); namely, (1) Those made up of a number of individual *wires* all laying *parallel* in the finished cable. (2) Those made up of a number of twisted wire *strands*, the strands all laying *parallel* in the finished cable. (3) Those made up of a number of wire *ropes*, the ropes all laying parallel in the finished cable.

The one thing that all three types have in common is that the unit members as delivered to the field are finally laid parallel in the cables. Wherein they differ is in these units:

- (1) Wires (2) Strands (3) Ropes

Then why not adopt as standard terms:

1. Parallel Wire Cables (universally recognized)
2. Parallel Strand Cables
3. Parallel Rope Cables

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Spinning--The Progressive Step

In Erecting Long Span Parallel Wire Cable Suspension Bridges

IN 1883 when the Brooklyn Bridge was completed, it was then the largest suspension bridge ever built, and it has held this record for many years. In fact, when the length of the cables from anchorage to anchorage is considered, the record was not broken, until the event of the George Washington Bridge, with the exception of the Ambassador Bridge, and then only to the extent of 100 feet—a record of almost a half-century. In point of main-span cables, however, there have been some notable increases in lengths which are readily seen in the table preceding page 1 which also shows other interesting comparative data.

The underlying principles involved in the erection of the cables for all of these bridges, are fundamentally the same and while, quite naturally, there have been improvements and refinements, in the methods used, these principles remain essentially unchanged.

Many said that the building of the Brooklyn Bridge was the dream of a visionary—but, it was done. It has only been a few years ago when the construction of a span as long as the George Washington Bridge was pronounced impossible by high authorities, and later it was deemed to be practical, but believed to be unprofitable—but, it has been done.

So, we continue to build suspension bridges of unprecedented dimensions, increasing the length of the spans and

the diameter of the cables without materially changing the basic principles of parallel wire bridge cable construction. There have been, however, essential developments that have made these great strides possible.

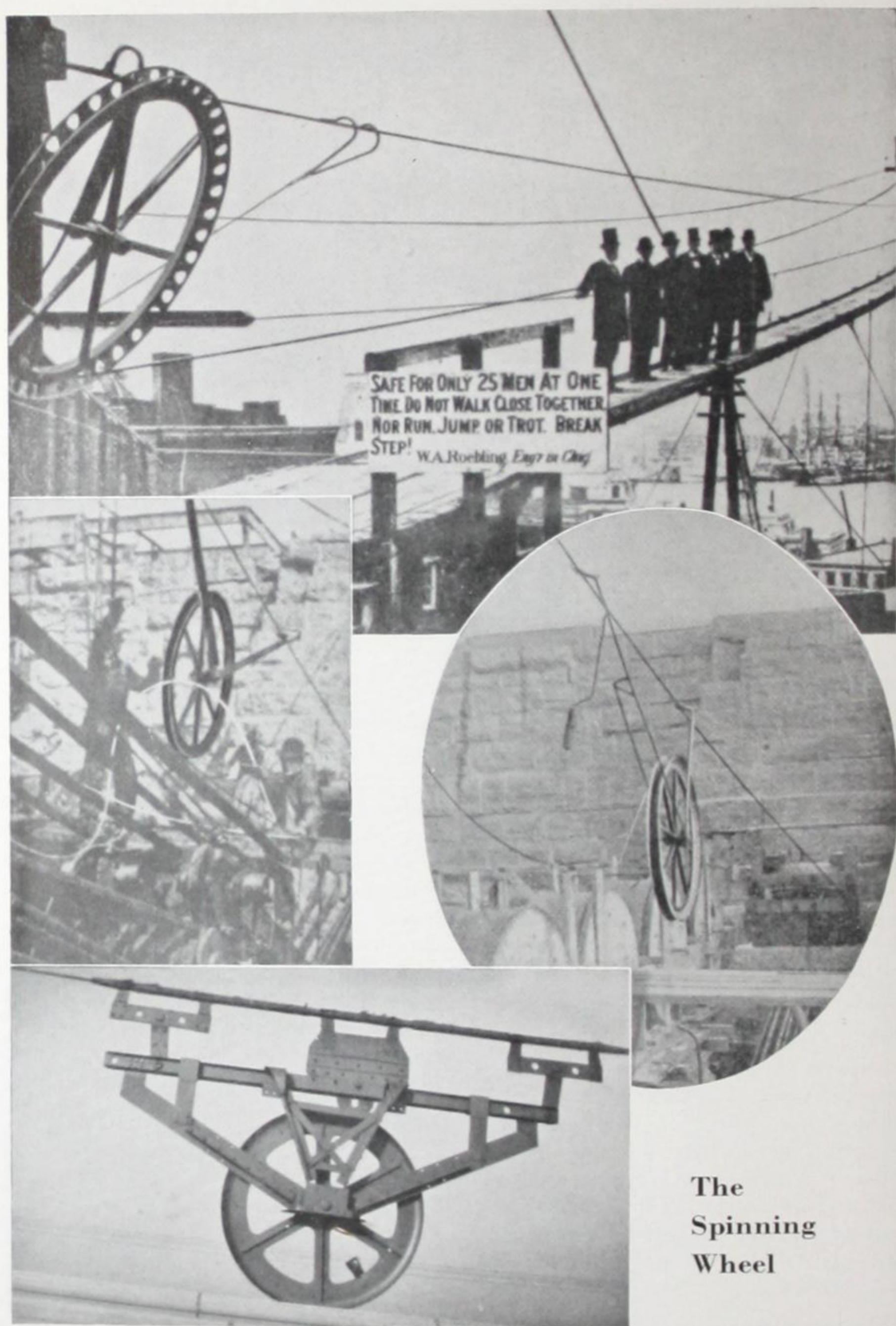
These developments are seen in the creation of new high standards of application, improved scientific and mechanical investigations, methods and equipment, that have assured great safety, efficiency and economy, never before approached in bridge building. Without these the building of the George Washington Bridge could not have been done with such speed and proficiency as has marked this achievement.

With the background of tradition, experience and accomplishment that has been sketched for our readers, the Roebling Company was eminently qualified to undertake the long, difficult and costly research and design, resulting in more than thirty new features and details of equipment and method, which have played such an important role in the erection of the main cables of the George Washington Bridge—the largest suspension bridge to date.

This apparent sudden step forward, does not mean however, that the development of the *Roebling Idea* in suspension bridge building has lain dormant from the erection of the Brooklyn Bridge until that of the George Washington Bridge. The increasing length of the spans and other require-



The George Washington Bridge Cable



The Spinning Wheel

Important Steps from Brooklyn Bridge to George Washington Bridge

ments has been any great "jump" and changes in the location of the base a natural development. The principles of the spinning method first used on the Brooklyn long-span suspension bridges even

Reference again to the comparisons, showing that to make the George Washington such an outstanding achievement. There is another aspect of this tabulation of the speed of the cables. This, we believe, is the one big advance in parallel-wire spinning. Practically all the cables, referred to as application and accomplishment.

The speed of the wire has been spun has been the record made. The spinning of the wires for the George Washington Bridge at a speed of 330 feet per minute. Williamsburg Bridge increased to 400 feet per minute. The Manhattan Bridge was accomplished. The George Washington Bridge was 700 feet per minute. What the record for long-span parallel-wire spinning is one that will be remembered by the "minded" people.

The importance of this achievement can be realized that the George Washington Bridge contained 21,000 cable-length of wire. The age to anchor the George Washington Bridge of 105,896 wires.



ments has been gradual and without any great "jumps", so the modifications and changes in the methods of application of the basic principles have been a natural development. In these basic principles is included the aerial spinning method for the cables that was used on the Brooklyn Bridge and on all long-span parallel wire cable suspension bridges ever since.

Reference again to the table of comparisons, shows the items that combine to make the George Washington Bridge such an outstanding accomplishment. There is another factor, however, that this tabulation does not develop, and that is the speed with which the spinning of the cables has been accomplished. This, we believe, may be selected as the one big advance in the building of parallel-wire suspension bridge cables. Practically all of the thirty-three features, referred to above, find their application and result in this one big accomplishment.

The speed with which the cables have been spun has more than doubled since the record made on Brooklyn Bridge. The spinning wheels carried the cable wires for the Brooklyn Bridge at a speed of 330 feet per minute, on the Williamsburg Bridge this speed was increased to 400, and with the Manhattan Bridge a further increase to 460 was accomplished. Whereas, with the George Washington Bridge a speed of 700 feet per minute was the record. What the record will be on the next long-span parallel-wire cable bridge is one that will keenly interest "bridge-minded" people.

The importance of this accomplishment can be best appreciated when we realize that the Brooklyn Bridge cables contained 21,432 wires with a total cable-length of 3,578 feet from anchorage to anchorage, and the George Washington Bridge cables with a total of 105,896 wires measured 5,212 feet.

Let us, for a moment review some of the developments that have made this great advance possible.

The Spinning Wheel

The first progressive step we note is the development of the spinning wheel. The spinning wheel for the Brooklyn Bridge was of light wooden construction with a zinc rim, as is indicated in group. A vertical metal goose-neck frame carried the wheel. The frame was braced against the pull of the loop of wire by a guy to a point on the hauling rope in front of the wheel. The lower end of the frame was counterweighted to prevent overturning by the wind.

Up to the time of the George Washington Bridge, the goose-neck frame was used with the two legs to the frame in the shape of the legs of a triangle. This permitted the use of the wheel in both directions. The construction of the wheel also remained of light wood with a metal rim. For the George Washington Bridge, however, the goose-neck frame was replaced by a split sheave assembly. The half-sheave flared downward to give clearance to the spinning wheel as it passes these supports. The sheaves at the top were brought close enough together to support the hauling rope and far enough apart to allow passage of the vertical hangers on the spinning-wheel frame. The frame which hung directly below the rope was of structural steel and triangular in shape, carrying the wheel at the apex. The wheel itself consisted of a cast steel hub and two sides of pressed steel bolted together to form spokes and rim. Maple wood was used for the tread at the rim.

Increasing Number of Wires Spun

On the Brooklyn Bridge each of two endless-wire rope tramways, carrying two spinning wheels, took wire over for two of the four cables. Wires were

taken over from the Brooklyn side only so that the wheels returned empty to that side.

On the Williamsburg Bridge one tramway, and two wheels, served two of the four cables; but wires were taken over from both sides, and no wheel ran empty.

For the Manhattan Bridge, and on bridges since that time, one tramway with two wheels served one cable, and wire was spun from both sides.

This meant that on the Brooklyn Bridge only one strand for each cable was spun at one time, and on the Williamsburg Bridge, only two strands for one cable were spun at one time. For the Manhattan Bridge, and continuing since, four strands per cable were spun simultaneously.

Previous to the erection of the George Washington Bridge, the spinning of the strands was done with the anchor shoes horizontal. This required the shoe to be turned through 90° to anchor between eyebars set in the vertical plane. The George Washington Bridge strands were spun with the shoe vertical and pulled back between eyebars (set in the vertical plane) without any swiveling.

Adjusting the Wires

Another progressive step is found in the methods used in adjusting the wires. In adjusting the wires of the Brooklyn Bridge, ten platforms, or cradles, were used, supported by ropes continuous from anchorage to anchorage. There were three cradles in the main span, and one in each side span for each pair of cables. The adjustment took place from the ends of these cradles—one strand hanging just within reach at each end.

The cradles carried the supporting sheaves for the tramway ropes. These cradles were reached by a footbridge 3 ft. 6 in. wide from anchorage to anchorage. Previous footbridges had been

suspended from the footbridge cables, but for the Brooklyn Bridge the section rested directly on the cables. The sections were made entirely of 3" x 12" oak stock and connected to footbridge ropes by "U" stirrups. The sections rested on $2\frac{5}{8}$ " diameter steel wire ropes and $1\frac{1}{4}$ " diameter steel wire ropes just above the section were connected to them by the same "U" stirrups.

Like the Brooklyn Bridge footbridge sections, the main span sections for the George Washington Bridge were each 12 feet long, and also like the Brooklyn Bridge, were erected from the center of the span to the towers.

Because there were no footbridges from which the cables of the Brooklyn Bridge could be reached, all strand seizing, cable seizing and cable wrapping, had to be carried on from boat-swain chairs or trolley. Wrapping of the cables was carried on from a trolley carriage.

Instead of manila rope hand tackles being used, as previously, for wire adjustment on the George Washington Bridge, small electric hoists with remote control, furnished the power for pulling the wires up to adjustment.

Elevation and Position of Strands

The changed elevation and position during the spinning of the strands has had much to do with the increased speed.

The Brooklyn Bridge strands were spun at an elevation 57 feet above the finished cable elevation at the center of the span. The decrease in deflection raised the tension to serve as a test of both wire and splices. The difference in length was taken care of by setting the strand shoes during spinning, twelve feet behind their permanent pins in the anchor eyebars. A tension of 75 tons was developed in each strand of 282 wires; while for the George Washington Bridge, a tension of 130



tons was developed in each strand of 434 wires.

The Williamsburg Bridge was spun at an elevation 57 feet above the cable position at the center of the main span. The shoe being used was in the position at the center of the main span. The footbridge was used as a working platform in their spinning position. The platform was parallel to the position. The distance between these two platforms was 12 feet.

The Manhattan Bridge was spun parallel to the position by setting the

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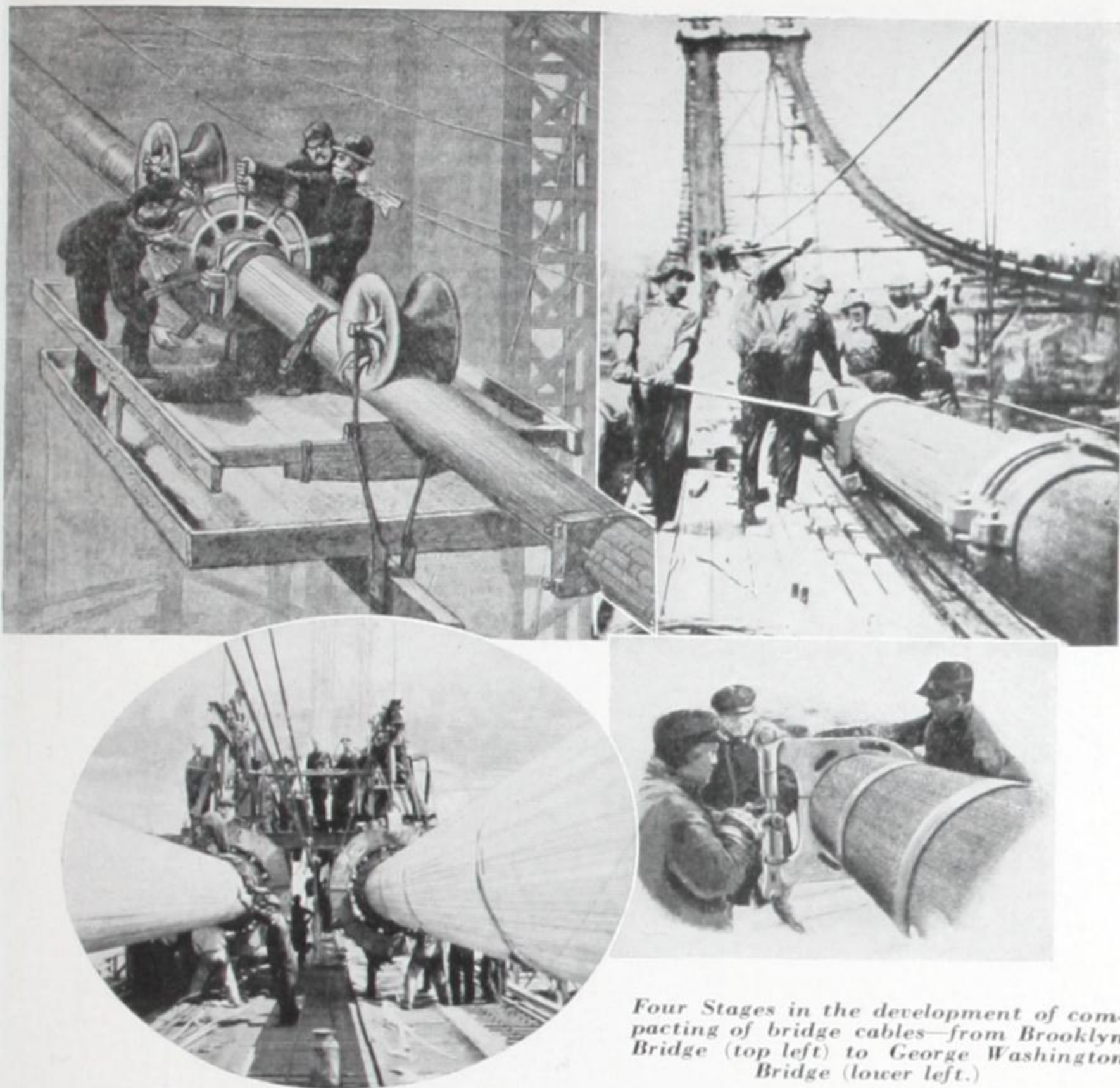
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Four Stages in the development of compacting of bridge cables—from Brooklyn Bridge (top left) to George Washington Bridge (lower left.)

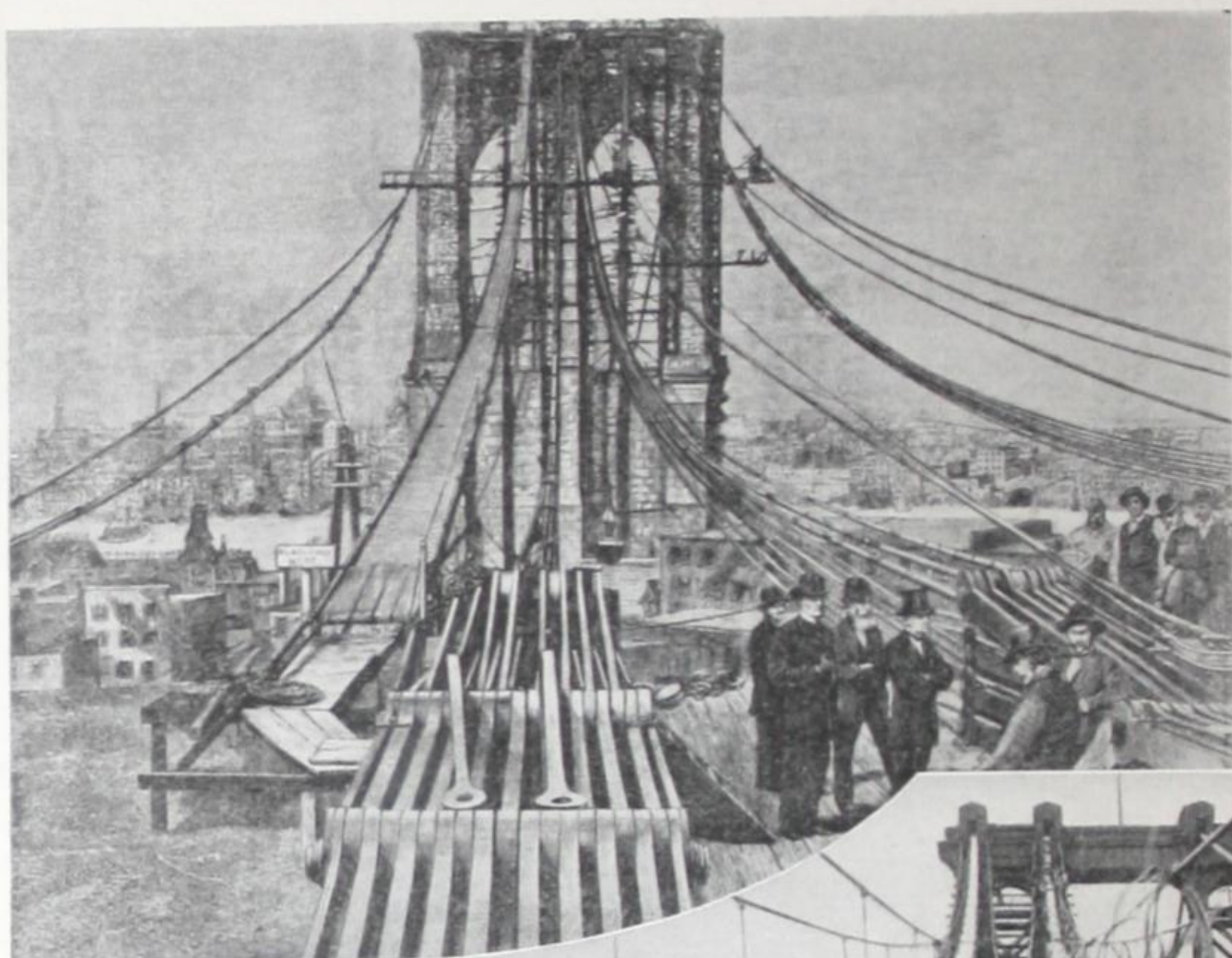
tons was developed for each strand of 434 wires.

The Williamsburg strands were spun at an elevation of 15 feet above finished cable position at center of main span; the shoe being 3 feet behind its final position at the anchorage. For a portion of the main span near the center, the footbridges divided to form one working platform parallel to the strands in their spinning position, and another platform parallel to the finished cable position. The vertical difference between these at the center span was 14 feet.

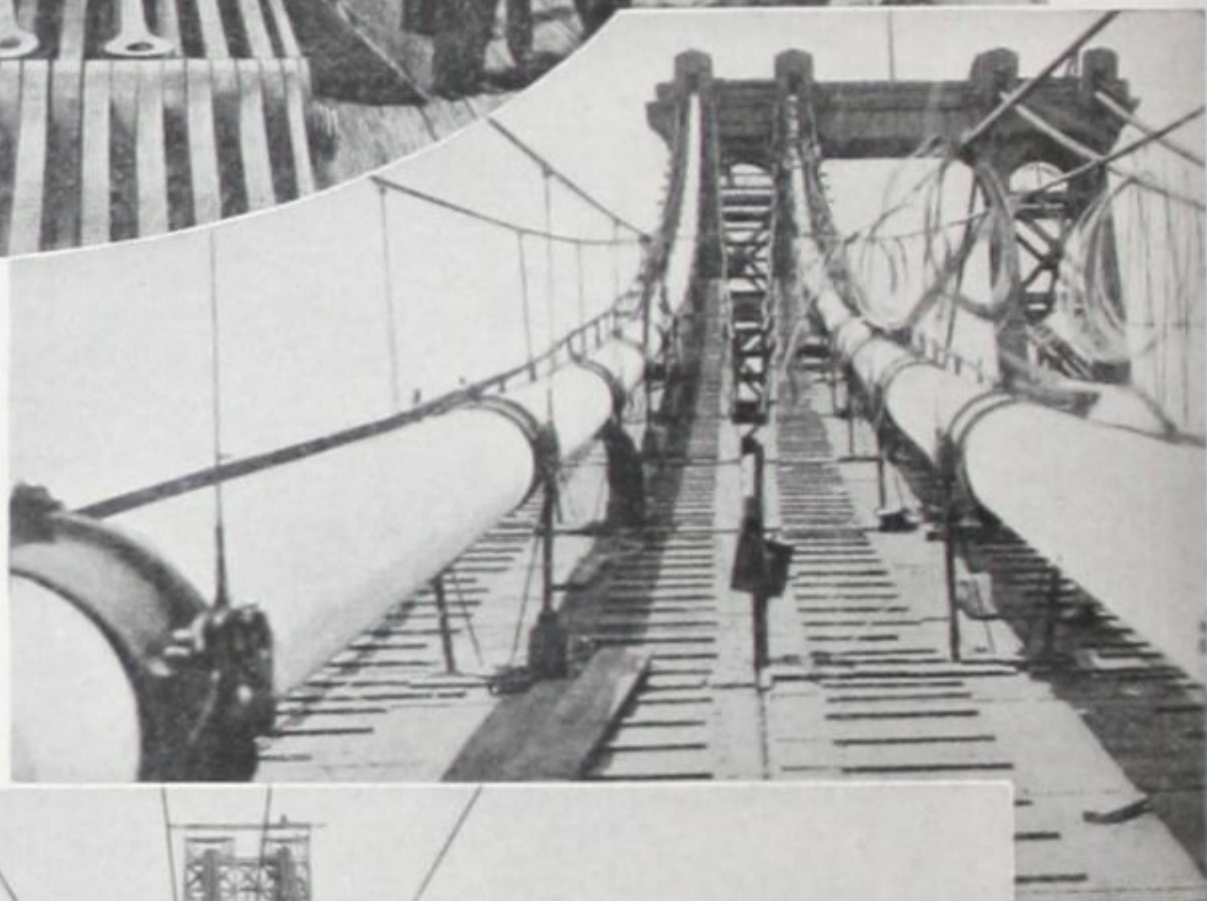
The Manhattan strands were spun parallel to the finished cable positions, by setting the shoe two feet in front of

its final position at the anchorage. Since the Manhattan Bridge this same procedure has been followed.

For handling the pull of the Brooklyn Bridge strands at the anchorage, a twelve part wire rope tackle was slacked off by an eight part manila rope tackle attached to the lead line. The lead of the manila rope tackle was connected to a steam hoist. The tension on the wire rope lead was eight tons and the tension on the manila rope lead one and one-half to two tons. The strands for the Brooklyn Bridge were spun directly over the tower top saddle. The lifting of the strands from the spinning supports, which were then removed, and the lowering into the



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saddle was accomplished by lashing the strand with wire rope to a balance beam six feet long. Connected to the balance beam was a $3\frac{1}{2}$ -inch diameter threaded bolt. A nut and plate washer on the bolt was supported by a timber frame directly above the saddle. The turning of this nut by a large cast iron socket wrench with a timber handle, raised or lowered the strand.

For the Williamsburg Bridge, the same method was used for raising and lowering the strand, except that a roller bearing was used under the nut and a ball and socket joint was added to take care of the drift necessary to lift the strands from either side of the saddle. At the anchorage, steamboat ratchet jacks were used to slack the ends of the strands to their permanent position.

A more definite change was effected, however, for the Manhattan Bridge, where chain falls were used to handle the strands on the tower tops, and hydraulic jacks used for pulling the strands at the anchorage.

A still more advanced method was used for the George Washington Bridge. Here the tower-top lifting was done by an electric crane. The anchorage turning point lifting was done by a hydraulic jack and the anchorage pulling done by another hydraulic jack. The lifting has always been done by using the balance beam method.

Tramways and Footbridges

The erection and design of tramways and footbridges have been important factors in the speeding up of the spinning process and other operations on the cables.

On the Brooklyn Bridge one length of $\frac{3}{4}$ -in. tramway rope was laid out along the river bottom and over the towers and then hoisted into the air. On this rope another similar rope was taken over and connected to the first to form an endless tramway. A $1\frac{3}{4}$ -in. rope was taken across on this tramway.

Thereafter, the $1\frac{3}{4}$ -in. rope served as a carrier cable for all other ropes taken across by the tramway.

The footbridge ropes for the Williamsburg Bridge were laid out three at a time on the river bed from a barge with the ends taken to the anchorage across rollers on the tower tops. Pulling in at one anchorage brought the rope clear of the water, and to the desired sag in the spans.

The same procedure was used in erecting the footbridge ropes for the Manhattan Bridge, except that four ropes were laid out at one time.

Later a slightly different procedure was developed. The ropes were laid out along the river bed as before, but not across the towers. At the towers the ropes were picked and placed across tower top supports by derricks on these tower tops.

Up to the time of the George Washington Bridge erection, footbridge ropes were continuous, anchorage to anchorage, and the adjustment was made at the anchorage. Each George Washington Bridge footbridge rope was separated into three parts, one main span length and one length for each of the side spans. All adjustment was made on the tower by means of the links connecting the main and side span lengths.

The Brooklyn Bridge tramways were supported by bents at five points other than the towers. This condition was the same for the Williamsburg Bridge. Nine bents supported the Manhattan tramways. The spacing of these bents was about 400 feet for both Brooklyn and Williamsburg, and 250 feet for Manhattan. For the George Washington Bridge, the spacing was 216 feet.

Previous to the George Washington Bridge, footbridges, tramway bents, and cross-bridges were of timber. For the George Washington Bridge these portions of the spinning equipment were of

steel. The flooring for the footbridge sections and cross-bridges were, of course, timber.

For the first time, the footbridge sections of the George Washington Bridge were erected as a complete section from trolley carriages on the footbridge ropes.

The Control of Unreeling a Factor

Up to the George Washington Bridge, the reels of bridge wire were turned by the pull on the wire from the wheel taking the loop across, and manual braking was used to obtain, as near as possible, uniform unreeling. On the George Washington Bridge, the wire reels were unreeled and also braked by power with variable and practically instantaneous control. The rise or fall of a weighted sheave riding on a loop of the wire coming off the reel, indicated to the unreeling operator in what manner the wire was keeping pace with the spinning wheel, and allowed him to control the unreeling speed accordingly.

In describing a bridge cable it is usually referred to as containing so many strands of a certain number of wires laid parallel in position, and the cable so many feet long. This suggests that there are actually separate lengths of wire laid in this parallel formation, whereas in reality, there are only two ends in each finished strand. When the wire comes to an end as it leaves

the reel, the end is fastened to the beginning of the wire from a new reel, by a little coupling. The general practice has been to cut a screw thread on the two wire ends and secure them with a coupling which is supplied with a right and left thread. This has effected a connection of approximately 95% of the wire strength, and it has not been an unusual occurrence for these couplings to become unscrewed as the wire releases its natural twist in the spinning process. In consequence of which a great deal of time is lost in this operation.

Therefore, with the George Washington Bridge a coupling of special design and material was used, in which the two wire ends were held by compression, developing a connection of approximately 100% of the wire strength. The coming apart was the unusual occurrence. This little coupling has been an important factor in the "speeding-up" of the spinning process—it is a *Roebling Idea*.

No, this is not all that can be said about these several steps or the many other less important steps that have combined to "speed-up" the spinning of the many types of wires required in bridge cables. Thus, we bring this story to an abrupt end with the realization that while we have not covered every minute detail, we have touched the high points in this important phase of modern suspension bridge building.

The C

IN the fall of 1909, the breaking of the George Washington Bridge, a particular attention was given to the traffic convenience.

In the fall of 1909, the bridge was later—the bridge was a fact, and the opening of the connecting link between New Jersey.

progress in suspension bridge building, let us think of the comparison with the building time of the bridge.

To some people, the Fort Lee Bridge is a larger number of the bridge on the Hudson River is the George Washington Bridge.

This bridge is at Fort Washington, between 178th and 179th Streets, Fort Lee, New Jersey. The completion of the bridge was in 1909.



The George Washington Bridge

IN the fall of 1927 the formal ground breaking for the George Washington Bridge claimed the attention of the reading public and the particular attention of the populace who were most benefited by this new traffic convenience.

In the fall of 1931, just four years later—the bridge has become an accomplished fact, and October 24th, marked the opening of this new traffic connecting link between New York and New Jersey. As an interesting note of progress in suspension bridge building, let us think of these four years in comparison with the thirteen years as the building time for the Brooklyn Bridge.

To some people this new bridge is the Fort Lee Bridge; and to a much larger number it will always be the Hudson River Bridge, but officially it is the George Washington Bridge.

This bridge crosses the Hudson River at Fort Washington Point between 178th and 179th Streets, New York and Fort Lee, New Jersey.

The completion of this structure was

an epoch-making achievement in engineering and construction. Particular emphasis is placed on this accomplishment when it is realized that during the first forty years after the opening of the Brooklyn Bridge in 1883 and the Delaware River Bridge in 1926, the increase in main-span length was only 12 per cent., whereas, in the short period of time to 1931—five years—the George Washington Bridge reaches 3500 feet—an increase of 100 per cent.

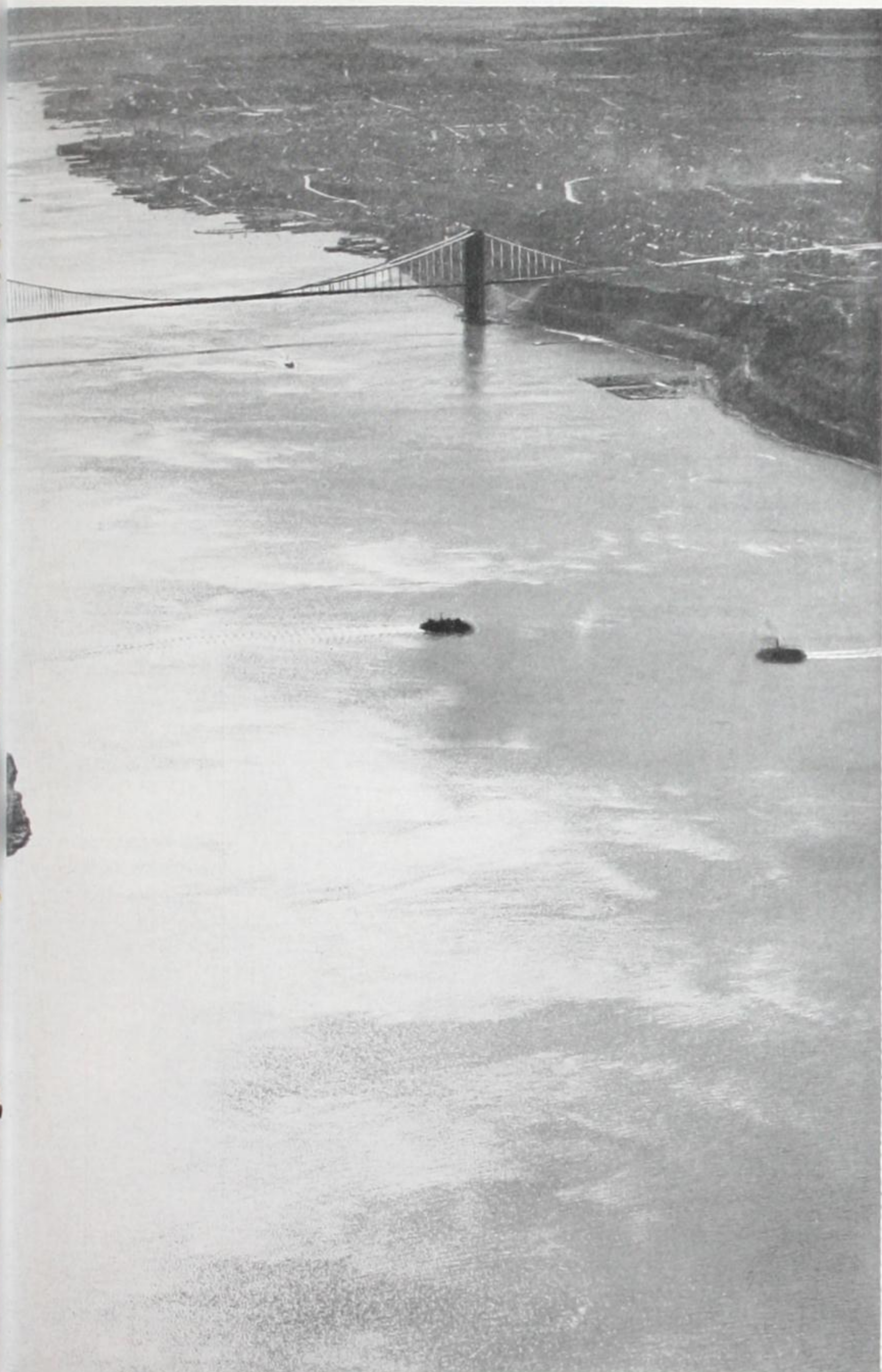
In designing the bridge, provision was made so that the capacity can be increased as the traffic grows. The bridge is now open to traffic and has two 28-foot-9-inch roadways and two sidewalks. Each roadway accommodates three lanes of traffic and with the liberal width of each lane—9 feet 7 inches—high-speed travel is permitted. There is another roadway, 30 feet 6 inches in width providing three additional lanes that can still be completed to accommodate increased traffic. The upper deck carries all of these roadways and the two sidewalks. The bridge capacity



Fig. 3—George Washington Bridge. An unusual airplane view showing the bridge in relation to lower New York. To the right of the skyscrapers in the distance can be seen the Statue of Liberty—a tiny speck. This, the longest suspension bridge in the world, crossing the Hudson River and connecting the states of New York and

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New Jersey, was opened to traffic on October 25th. Few, if any, pictures gives a better idea of the enormity of the engineering feat—its length as compared with the other bridges in this picture, and as compared with the width of Manhattan Island. It provides nine roadway lanes, four interurban rapid transit tracks and two sidewalks.

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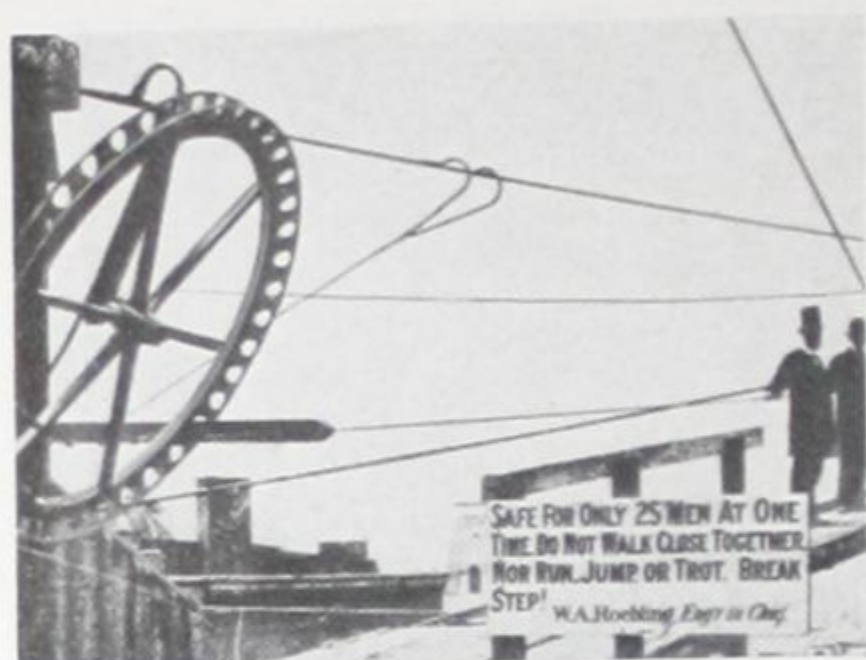


Fig. 3—Spinning Cable Wires on the Brooklyn Bridge

can be further increased as required, by the construction of the lower deck with a width of nearly 100 feet. The installation of either eight rapid-transit tracks or a combination of four rapid-transit tracks and one roadway for trucks and buses, is possible on this lower deck.

The towers, cables and suspender ropes, constituting the main supporting members of the bridge were originally constructed for the full capacity of the bridge. The increased capacity, as noted above, therefore, can be installed as required, without interfering with the general traffic. That the designing engineers fully appreciated the trend toward heavier vehicular travel at high speed, is evidenced in a cross-section study of the roadways.

The massive proportions and carrying capacity of this bridge can be best realized, by a comparison with the Delaware River Bridge at Philadelphia, which today is carrying a vehicular traffic far in excess of any bridge now in service. The suspended load of the

greatest bridge of all is 50 per cent. greater per linear foot of the bridge than the Delaware River Bridge, i. e., 39,000 lbs. per linear foot for the George Washington Bridge and 26,000 lbs. for the Delaware River Bridge.

Consider for a moment what this means: a 50 per cent. greater load per linear foot with 100 per cent. greater and longer span. It is not surprising therefore, that the required strength of the cables for the George Washington Bridge is three times greater than that for the Delaware River Bridge—360,000 tons strength of the first, and 120,000 tons for the second, the cable weight being 4.4 greater than the smaller bridge.

This data clearly indicates the magnitude of the engineering achievement

represented in the building of the George Washington Bridge—the longest suspension bridge in the world. The construction problem however, was one of even greater magnitude, taxing the skill of

the engineers to the maximum. This was especially true of the cable construction which required the creation of new high standards and the appli-



Fig. 4 and 5.—Types of Spinning Wheels used between erection of the Brooklyn and George Washington Bridges

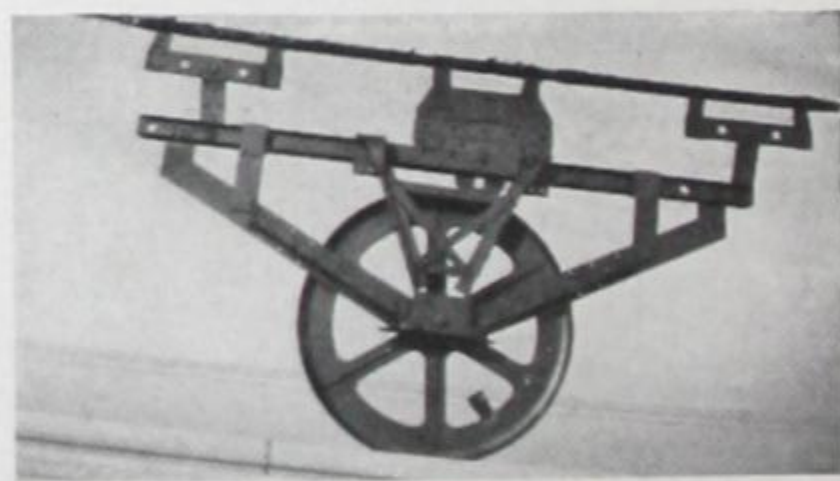
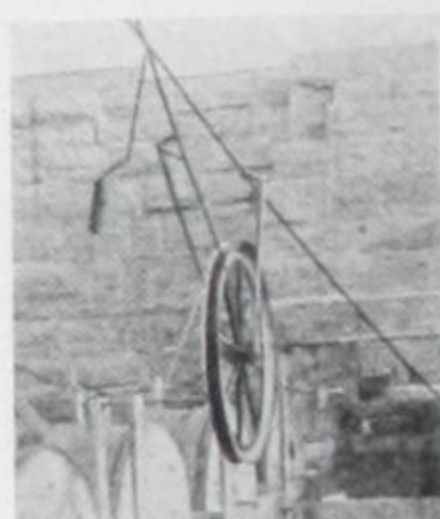


Fig. 6.—The Sheave Assembly Spinning Wheel used on the George Washington Bridge

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Fig. 4—The
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cation of scientific and mechanical investigations resulting in improved methods and equipment that assured greater safety, efficiency and economy than ever before approached in similar work.

The cable construction for the George Washington bridge was Roebling's particular responsibility. In the design and construction of suspension bridges and bridge cables, uninterrupted since 1849, John A. Roebling and his successors have originated and perfected many features essential to the success and safety of the George Washington Bridge cable work, among them being the following:

1. The use of wire spinning wheels.
2. The aerial cable spinning process.
3. Tramways for cable wire spinning.
4. The use of erection foot bridges.
5. A new type of wire spinning wheel and wheel carriage, eliminating the goose

neck that limited spinning speed.

6. Improved tramway supporting sheaves.

7. Erection of footbridges by tramway carriages

8. Erection of footbridges from midspan to towers with increased rapidity and safety.

9. Wire mesh flooring for erection footbridges.

10. Sectional footbridge cables.

11. Storm system independent of footbridges.

12. Suspended compression booms in storm system.

13. Preliminary stressing of footbridge cables and tramway ropes.

14. Automatic counterweight adjustment for storm system.

15. Maintenance of uniform cable wire tension by counterweight during stringing.

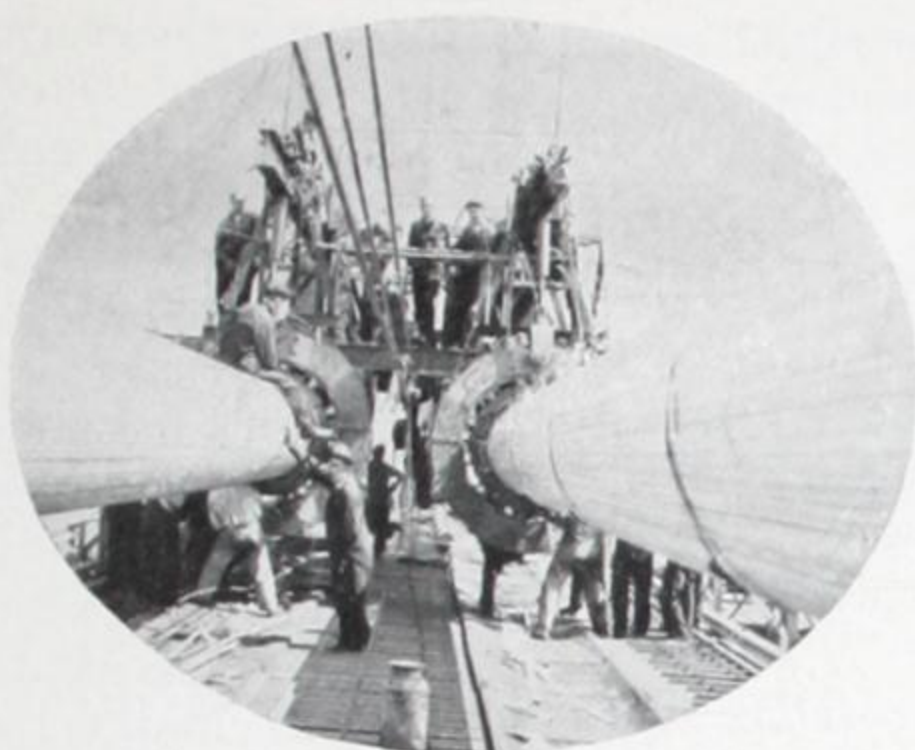


Fig 7.—Compacting one set of Main-Span Cables.

Fig. 8—The Unwrapped Cable ready for wrapping.



Fig. 8.—The Wrapped Cable ready for finish of paint.

16. Instantaneous central control of all wire spinning operations.

17. Power-driven and power-braked cable wire reels.

18. Power adjustment of cable wires.

19. Stringing cable wires on strand shoes in vertical planes.

20. Cable wire splices of practically 100 per cent. efficiency.

21. Measuring suspender ropes under high-tension.

22. Two-stage compacting—preliminary and final.

23. High-speed, high-tension cable wrapping.

Eliminating the first four features of this list, the following 19 were the result of two years' scientific and mechanical investigation in the laboratories of the

Roebling Company and were developed for cable erection of the George Washington Bridge.

Originally the actual date for the completion of the bridge was a more or less open date during the summer of 1932. The speed of construction by the several contractors, however, including cable erection, so advanced the work that the opening date was brought forward to the fall of 1931.

The cable contract called for the completion of one set of two cables to be finished by December 1, 1930, so that the erection of steel suspender ropes could be commenced. The second set of two cables to be completed one year later, December 1, 1931. However, through improvements developed by the Roebling Company, it was possible to complete all

cables ready for the erection of the steel suspender structure on October 28, 1930. Thus we see that the first set of cables was finished over one month ahead of the contract, and at the same time the second set was completed—13 months ahead of contract time.

If we review a tabulation of the various factors entering into suspension bridge building from the Brooklyn Bridge to the George Washington Bridge, it will be quite evident that the speed with which the spinning of cables has been accomplished can be



Fig. 9—Cable Bands in place and wrapping the Back Spans.

PHOTO—LEO AARONS



Fig. 10.—Cable-

considered the building of bridges.

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The speed wi cables have be has more than the record ma Brooklyn Brid spinning whee the cable wire Brooklyn Brid speed of 130 fe ute; on the V burg Bridge t was increased with the Ma Bridge a fur crease to 460;

Fig. 11.—The type of Cable-



Fig. 10.—The Robinson type of Cable-Wrapping Machine

considered the one big advance in the building of parallel-wire suspension bridges.

The entire group of features listed had an important bearing on the speed with which all operations of cable erection were accomplished, one third of them can be checked as having a direct bearing on the one big achievement—speed in cable spinning.

The speed with which cables have been spun has more than doubled the record made on the Brooklyn Bridge. The spinning wheel carried the cable wires for the Brooklyn Bridge at the speed of 130 feet a minute; on the Williamsburg Bridge the speed was increased to 400; with the Manhattan Bridge a further increase to 460; and with

the George Washington Bridge a speed of 700 feet was the record. The importance of this achievement can be best appreciated when we realize that the Brooklyn Bridge cables contained 21,432 wires with a total cable length of 3578 feet from anchorage to anchorage and the George Washington Bridge cables with a total of 105,896 wires measuring 5212 feet each. In the four illustrations, Figs. 3, 4, 5, and 6 (page 26) are shown the several types of spinning wheels which have been in use commencing with the Brooklyn Bridge (Fig. 3). The spinning wheel for the Brooklyn Bridge was a light wooden structure with a zinc arm and a vertical metal goose-neck frame carried the wheel. The lower end of the frame was weighted to prevent overturning by the wind.

Up to the time of the George Washington Bridge the goose-neck frame was used to two legs of the frame in

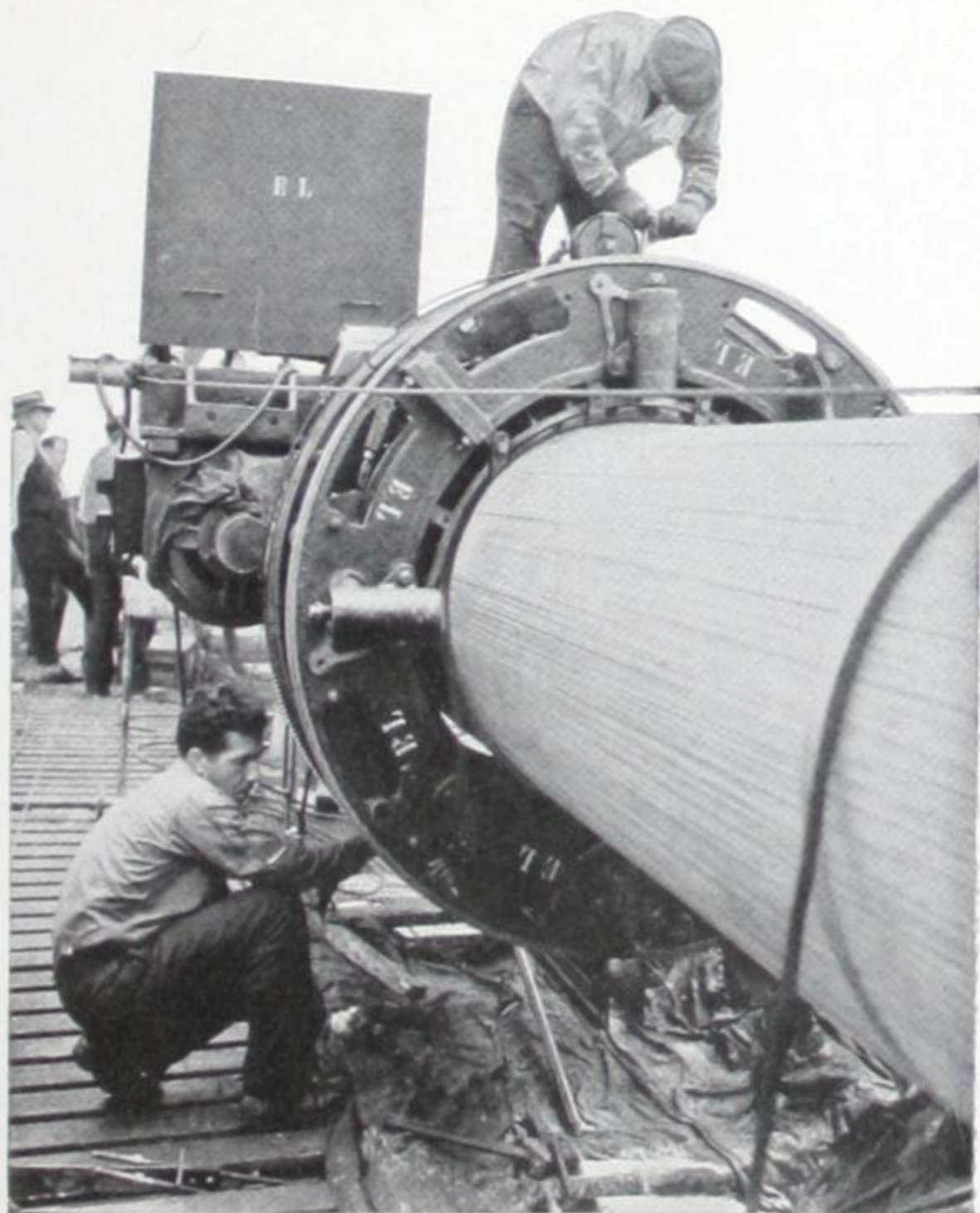


Fig. 11.—The Roebling type of Cable-Wrapping Machine.

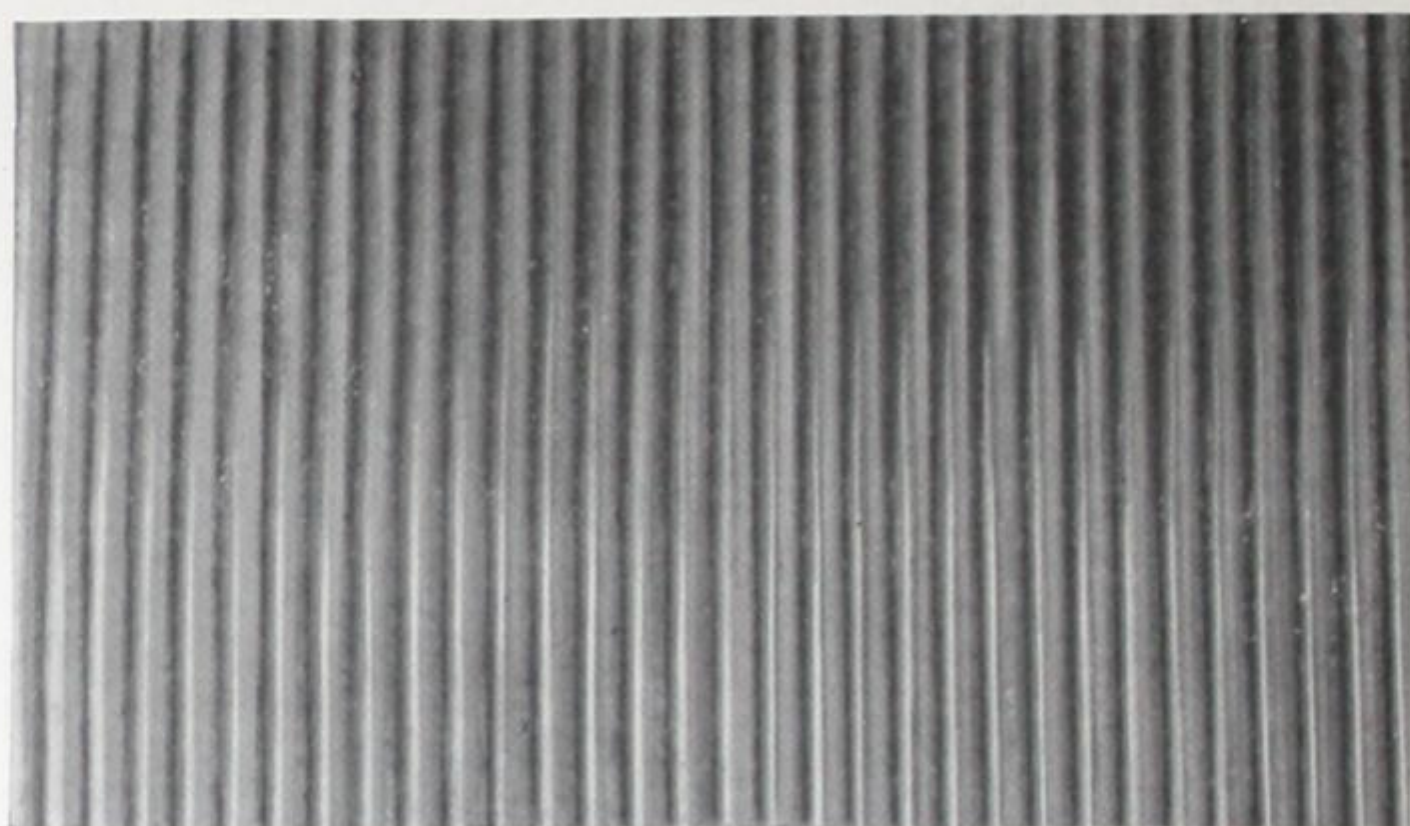


Fig. 12—A Close up—Cable Wrapping

the shape of the legs of a triangle, which permitted the use of the wheel in both directions. Construction of the wheel also remained of light wood with the metal arm, but for the George Washington Bridge the goose-neck frame was

replaced by the sheave assembly. (Fig. 6, page 26.) The half-sheaves flared downward to give clearance to the spinning wheel as it passes these supports. The sheaves at the top were brought close enough together to support the hauling



Fig. 13—The Finished Cables with the wrapping as slick as the skin on a snake

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rope and far enough apart to allow passage of the vertical hangers on the spinning-wheel frame. The frame which hung directly below the rope was of structural steel and triangular in shape, carrying the wheel at the apex. The wheel itself consisted of a cast steel hub and two sides of pressed steel bolted together to form spokes and rim.

Maple wood was used for the tread at the rim. On the Brooklyn Bridge each of two endless wire rope tramways, carrying two spinning wheels took wire over for two of the four cables. The wires were taken over from the Brooklyn side only so that the wheels returned empty to that side.

On the Williamsburg Bridge one tramway, and two wheels, served two of the four cables; but wires were taken over from both sides and no wheel ran empty.

For the Manhattan Bridge, and on bridges since that time, the tramway with two wheels served one cable, and wire was spun from both sides.

This meant that on the Brooklyn Bridge only one strand for each cable was spun at one time, and on the Williamsburg Bridge, only two strands for one cable were spun at one time. For the Manhattan Bridge, and continuing since, four strands per cable were spun simultaneously.

Spinning, compressing and wrapping may be considered the major field operations in bridge cable erection, and while spinning, as noted above, represents the operation in which the greatest comparative speed-gain has been made, compressing, or compacting (Fig. 7, page 27) has kept stride with the increasing demands in cables of greater diameter with the consequent greater weight of wire.

Wrapping, however, on the George Washington Bridge, not only shows an

increase in the speed of application, but a very much improved appearance in the finished result. This third field operation (see Figs. 8, 9, 11, 12, 13) on the George Washington Bridge as on all wire suspension bridges, followed after the bridge cables were compacted and the dead load of the bridge—road bed structures, etc. suspended therefrom—then the cables were ready for wrapping.

This operation consisted of applying a closely wound spiral of galvanized soft annealed wire around each cable from anchorage to anchorage. When the wrapping was in place, the outside surfaces of the cables were given three coats of paint: one heavy red lead coat, and two of aluminum. The wrapping wire, together with its paint, provides a water-tight shielding for each cable. The wrapping wire was applied with a new high-speed, high-tension type of wrapping machine designed by the cable contractors and used for the first time with great success on this bridge—(see Fig. 11). The high speed attained by the wrapping machines was made possible by first reeling or spooling the wrapping wire around the cable itself. Up to this time it has been common practice to spool the wrapping wire on small spools which are mounted on the wrapping machines, revolving on their individual axles, and then rotating about the main cables as shown in (Figs. 9 and 11).

A study of the two wrapping machines as illustrated by (Figs. 10 and 11) will give a pretty clear idea of the two methods, and the reason for the increased speed in cable-wrapping, which together with the other two operations—spinning and compacting—makes the erection of the George Washington Bridge cables an outstanding achievement in bridge building.

Wire Screening as Part of Footbridge

AN indication of the increasing use of wire screening—woven wire cloth—in various types of construction work is found in the accompanying illustrations of the footbridges

3. Reduced possibility of accident—which in the event of the spaces being left open, because of the first two items, would have been a serious cause of accident.



Fig. 1—Footbridge Showing Use of Galvanized Wire Cloth between Wood-planking Walkways

used in the cable erection of the recently completed George Washington Bridge.

Two footbridges were strung for each of the two sets of cables, from tower to tower and from tower to anchorage.

Each footbridge, of steel construction, carried three walks of wood planking and under the cables, two more walks of woven wire cloth. While not primarily designed for walks, the screening made the space available for such a purpose as is indicated in Fig. 1, and at the same time provided:

1. Reduced weight.
2. Reduced wind resistance.

4. Reduction in excessive or additional weight due to storm or rain.
5. Reduced fire hazard.
6. Provided easy handling and erecting.
7. Provided an easy and quick surface drainage.

The use of wire screening on various types of industrial, as well as construction bridges and scaffolds, for one or more of the seven reasons noted above, finds increasing favor among engineers and contractors.

The 1 in. mesh wire cloth (Fig. 5) was found to be particularly practical for the

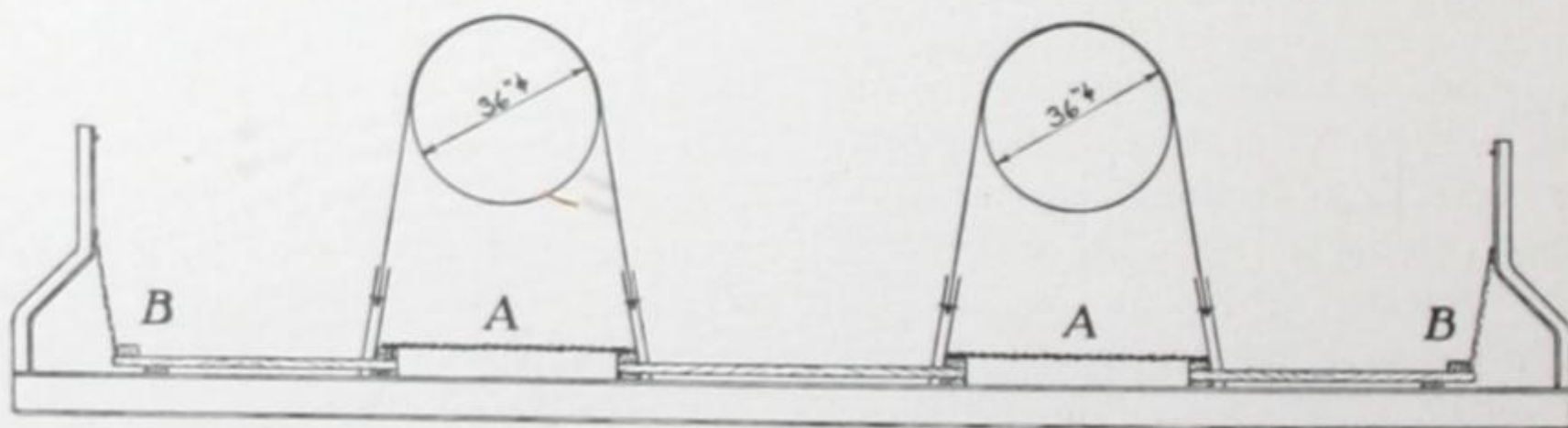


Fig. 2.—Cross-section showing the General Detail of Fig. 1
A. Heavy woven wire, see Fig. 5. B. Kickboard, using wire netting, see Fig. 4.

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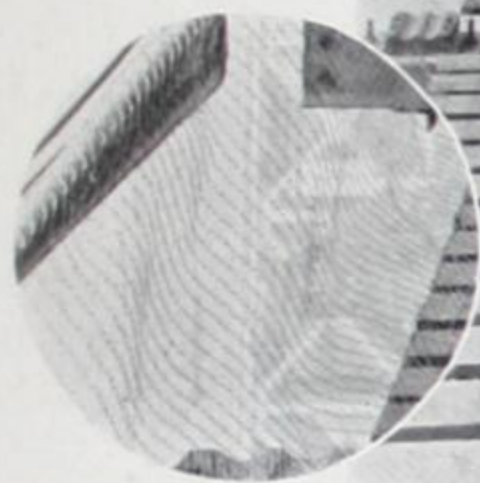


Fig. 5 Shows the actual size of the wire cloth used on the footwalks

deck of this footbridge as illustrated, but screening of even larger mesh is provided for similar purposes.

These bridges as first erected were supported on cables as indicated on each



Fig. 4.—"Jersey" Galvanized Wire Netting, 1 in. mesh (actual size) 30 in. wide used for the Kickboards on Footbridge

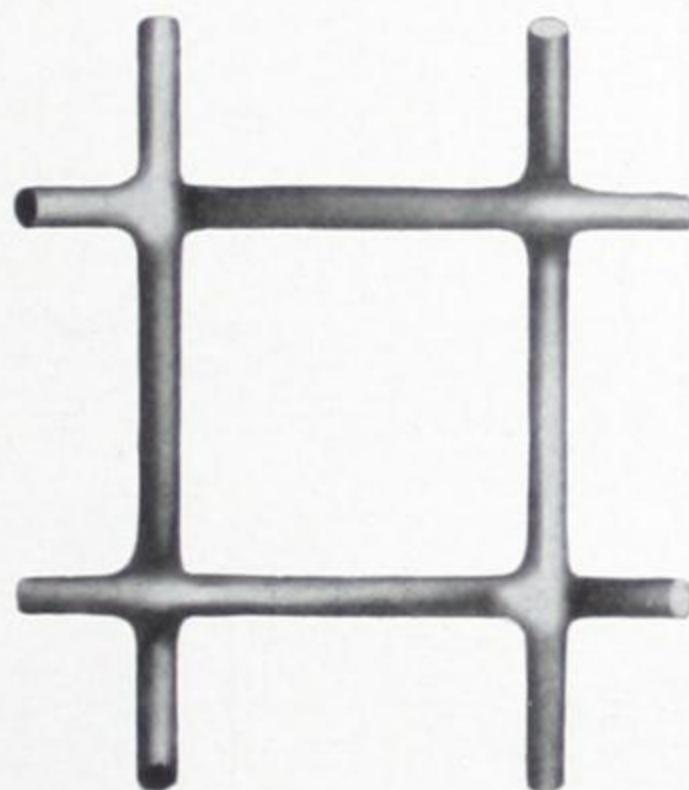


Fig. 5.—"Jersey" Galvanized Wire Cloth, 1 in. mesh, size 12-.105 in. diameter wire (actual size) used between wood-planking footwalks

side of Fig. 1. When the main cables were strung, smaller footbridge cables became the suspender ropes for the main structure, as is indicated in Fig. 3 and the footbridges were then suspended from the main cables. Fig. 3 also shows the partial removal of the wire cloth for placing of the suspender ropes and

illustrates the applicability of this product in construction work. The space is originally occupied by these suspender ropes, as footbridge cables as shown in Fig. 2, and indicated by the letter "B", were protected by the kickboard made of 1 in. mesh wire netting as illustrated in Figs. 3 and 4.



A DREAM REALIZED

Here the Builder of Bridge Cables sees the Realization of his Dreams. The Largest Suspension Bridge in the World carried on Cables made of Wire. He sees Wire Cables above all other Features

*George Washington Bridge over the Hudson River
connecting the states of New York and New Jersey*

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Manufacturing High-Modulus Footbridge Ropes for Fort Lee-Hudson River Bridge

Modulus of Elasticity of 6 x 37 Rope Increased from 12,000,000 to 18,000,000 Pounds Per Square Inch by Prestressing to 125 for Main Cables of Grand' Mere and St. Johns Bridges Per Cent of Working Stress—Process Applied Also to Strands

By C. C. SUNDERLAND

Chief Engineer of Bridges, John A. Roebling's Sons Co., Trenton, N. J.

Reprinted from ENGINEERING NEWS-RECORD, May 1, 1930

Prestressing—What, Why and How?

The prestressing of Wire Ropes and Cables is strictly a *Roebling Idea* and development and was first put into practical use in connection with the foot-bridge cables for the George Washington Bridge (at that time known as the Hudson River Bridge).

We cannot better describe the what, why and how of prestressing than to reprint here an article prepared by Mr. C. C. Sunderland, Chief Engineer of our Bridge Department and published in Engineering News-Record, May 1, 1930.

ONE of the First Problems confronting the cable-spinning contractor on the 3,500-ft. Fort Lee-Hudson River suspension bridge was the design of suitable foot-bridges from which the four 36-in. diameter cables of the bridge could be spun. No ropes so long as would be required to support these walks had ever been built for such exacting service. It was particularly important that the ropes have a uniform modulus of elasticity and that this modulus be as high as possible. Rope-making machines are built on the principle that manufacture must be done under considerable tension so that the wires will be closely compacted, but no machine available would make these $2\frac{15}{16}$ -in. diameter ropes so that they would compact

under a working load of 160,000 lbs. Therefore, it was necessary to stretch these ropes after fabrication, to loads in excess of the maximum working load, in order to eliminate erratic or excessive sags. The equipment necessary for this prestressing is described in this article. Some idea of the magnitude of the operation may be obtained from the fact that 185,000 ft., or 2,682,500 lbs., of rope were manufactured for these foot-bridge cables. This weight of wire is sufficient to construct the main cables for a 1,200-ft. span highway bridge with a 40-ft.-wide concrete roadway. The successful development of this process of multiple stressing is one of the most important advances made in the suspension-bridge field in many years. Already

this same equipment has been utilized to manufacture rope strands for the 949-ft. span Grand' Mere bridge in Quebec and for the 1,207-ft. span St. Johns bridge at Portland, Oregon. It is interesting to note that no footbridge cables are required for these last two structures, and that this method of construction is possible only by virtue of the development work occasioned by the design of the footbridge cables on the Hudson River bridge.

—Editor.

A WIRE ROPE is a very elastic structure. For example, in its manufactured state, a well-constructed wire rope, with an independent wire rope center, has a modulus of elasticity not much in excess of 12,000,000 when first stressed, as compared with a modulus of elasticity for the individual wires of between 25,000,000 and 27,000,000. For general use this high elasticity is desirable, since it tends to dissipate any sudden impact load. Although it is unusual for a new rope to fail, even under impact loads that calculations show to be in excess of the ultimate rope strength, ropes have failed under identical loads after having been in service for only a few months. Investigations of such failures generally show that the wires in the strands and the strands themselves have been worked into close contact in service, reducing the springiness of the construction and resulting in an increased modulus of elasticity.

When wire ropes are used for lift bridge counterweight cables, suspension bridge cables, suspender ropes and footbridge cables on large suspension bridges where accurate lengths and definite and uniform elastic properties are of major importance, it is necessary to fabricate the ropes with high tension and pressure, in order to approach more nearly the working tension of the rope in service. Proper manufacturing tension and pressure, together with accurately calculated wire sizes, will tend to assure

uniformity of the elastic properties, but even these careful methods were not sufficient to produce rope to meet the exacting requirements for the footbridge cables of the Fort Lee-Hudson River bridge.



Fig. 1—New Jersey Tower of Hudson River Bridge Showing Footbridges

Main cable spinning in progress. Framework on top of tower is runway for 200-ton traveling crane used to lift completed strands into saddles.

The two footbridges of this structure are supported by 36, $2\frac{15}{16}$ -in. ropes in four groups of nine ropes each. As is usual in suspension bridge construction, these ropes are later to be cut up and used as permanent suspenders. Although the most powerful and largest rope making machine in this country was used to manufacture these ropes, it was not possible to procure sufficient tension and pressure during the fabrication, to correspond to the working tension of the rope in service. It was therefore necessary to subject the ropes to additional stretching after they were manufactured.

When a rope is first subjected to working tension its elongation consists of both an elastic and a structural stretch. The elastic stretch is that portion of the elongation that shows full elastic recovery upon release of tension. The structural stretch is the elongation

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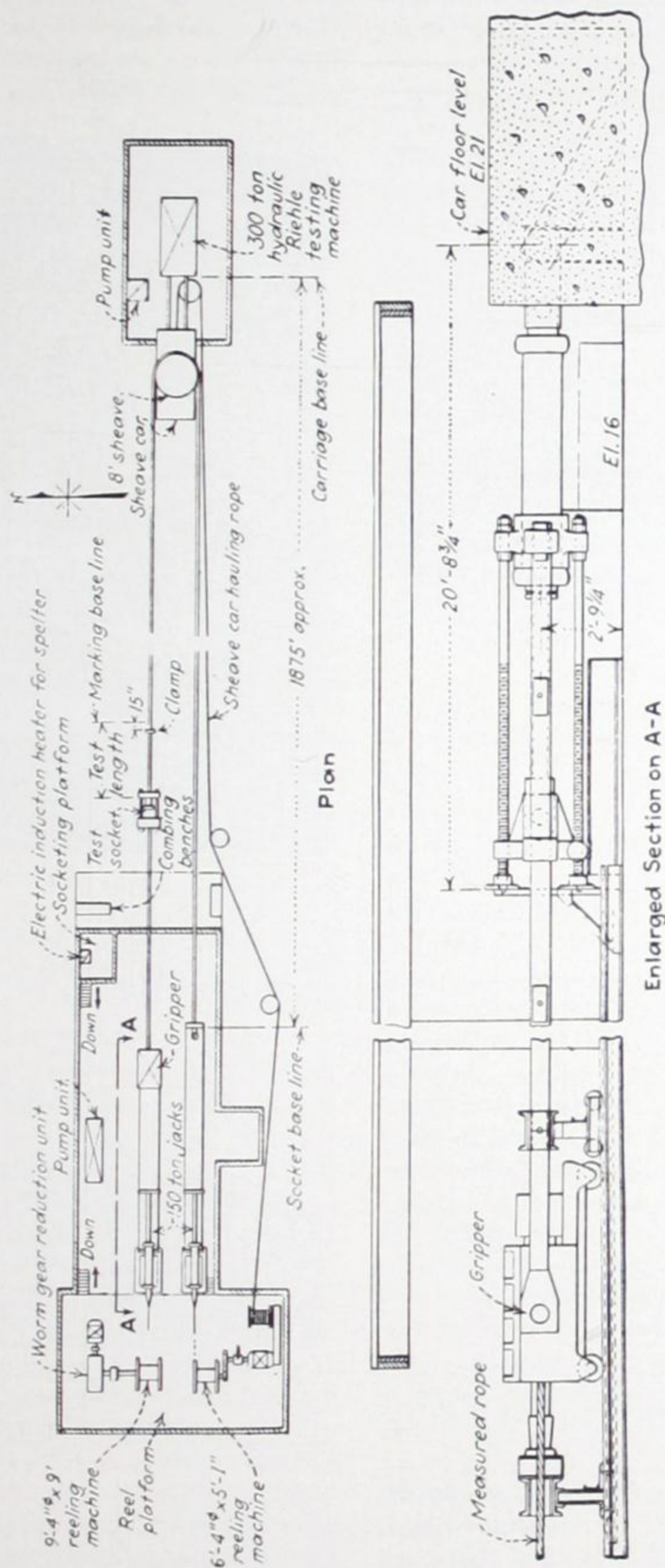


Fig. 2—Equipment Layout for Prestressing Wire Ropes in Lengths up to 3,750 ft.

which occurs over and above the true elastic stretch for any given tension, and does not show full recovery upon release of tension. The structural stretch is not a definite quantity, but is variable, depending on the size and power of the machine used to fabricate the rope, together with knowledge and skill of fabrication. For example, in studying the stress-strain diagram of the rope for the Fort Lee bridge, it was found that when any applied tension between the manufactured tension and the elastic limit of rope was held for a period of time, a continued elongation of specimen occurred. This additional elongation, without increase of load, was due to wires and strands seating themselves in closer contact, and was the structural stretch. Removal of this structural stretch was possible only by multiple stressing before erection.

Each footbridge cable is subject to approximately 160,000 lbs. working tension under normal loading, of which 80,000 lbs. is the approximate tension due to its own weight (14.5 lbs. per linear foot) in suspension on a 3,500-ft. span. The actual elongation of this length of rope between 80,000 and 160,000 lbs. tension is very important, since the footbridges must be located at just the proper height to permit construction of the main cables. Any uncertainty as to the structural stretch and permanent set of ropes between these tensions would nullify the careful computations for determining the unloaded deflection of the footbridge cables. We consider the structural stretch removed when the rope shows well-defined and uniform elastic stretch and recovery and when the load is maintained for some time at 80 per cent. of prior stressing without showing any additional elongation of specimen.

The ropes were fabricated on an 80-ton rope machine in our Trenton plant, in sets of 7,200-ft. lengths. Each set was then cut in two, wound on reels 9 ft.

in diameter and shipped to the plant at Roebling, N. J., where the prestressing, measuring, socketing and re-reeling equipment is located.

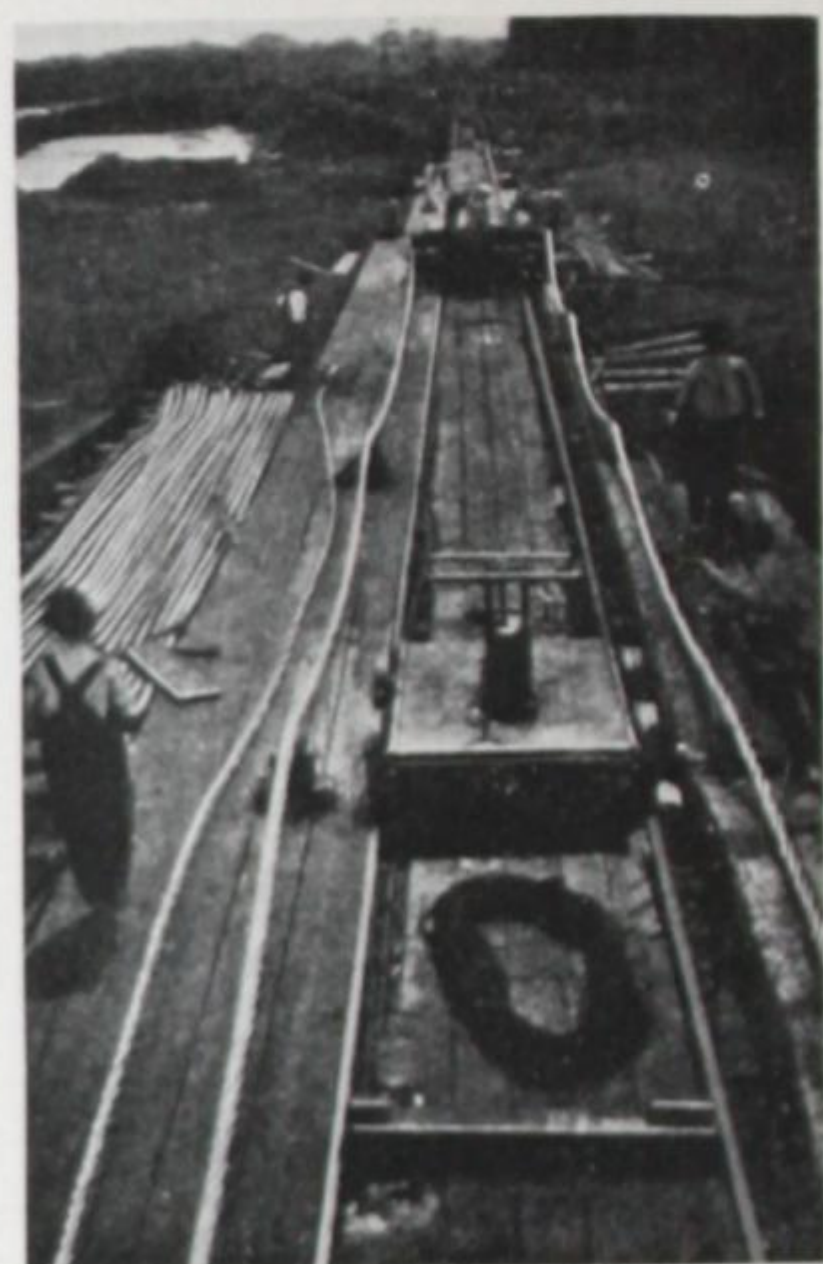


Fig. 3—Looking East Along the Prestressing Track

The special car around which the rope passes and which is attached to the testing machine at the east end is shown.

With the equipment as installed (Fig. 2, page 37) it is possible to stress a 3,750-ft. rope to a tension of 300,000 lbs., or a 1,875-ft. length to a tension of 600,000 lbs. A tension of 200,000 lbs. was applied to the 3,600-ft. ropes of the Fort Lee-Hudson Bridge. The equipment consists of a straight standard-gauge railroad track, 1,850 ft. long, running approximately east and west, at each extremity of which is located a building. The building at the east end houses a 600,000-lbs.-capacity horizontal hydraulic tensioning testing machine, while the west end building contains apparatus for reeling, stressing, gripping, cutting and socketing. Running on this track is a specially designed car (Fig. 3) on which is mount-

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Fig. 4—West End

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ed a horizontal sheave, 8 ft. in diameter. Along each side of the track and 8 ft. apart are 9-in. wide-mouth sheaves set at 25-ft. intervals; these sheaves support the rope being stressed. The stressing equipment at the west end consists of two 150-ton hydraulic pulling jacks (Fig. 2) set 8 ft. on centers, symmetrical about the center line of the track. These jacks have a ram stroke of $5\frac{1}{2}$ ft. and operate under a maximum pressure of 6,000 lbs. per sq. in. The outer end of the ram is carried by a crosshead type of carriage and through this head, above and below the ram, are two screw rods.

The rods, which serve as a safety device when tension is being held on the strand for a long period of time, are fastened to a yoke which encompasses the barrel of the jack and which also bears against the head of the jack. Passing through the sides of the crosshead and the yoke are two structural steel bars 1x8 in., having 3-in. holes spaced 5 ft. on centers. By pinning these bars to the yoke and removing the pins in the crosshead, the load is held by the yoke until the ram is run out, or in, for a new hold. In this way a total movement of 20 ft. on one jack and 25 ft. on the other is possible. Attached to the side bars of the north

the south jack there is a specially designed receptacle for the socketed end.

For the socketing operation there is a vise mounted on a platform about 10 ft. above the floor. Leading up to the vise is a guide with clamps attached, which holds the rope in a straight line vertical



Fig. 5—Measuring a Rope after Multiple Stressing

position, to assure that the socket, when put on, is not skewed with respect to the axis of the rope. Immediately in back of and above the jacks, are two reeling machines, one to take a reel up to 6 ft. 4 in. diameter and the other to take a reel up to 9 ft. 4 in.

In general, the procedure involved in the prestressing and measuring of the rope is as follows: The reel of rope, as received from the fabrication shop, is mounted in one of the reeling machines and the end pulled out and socketed. This socketed end is put into the receptacle attached to the south jack, and a bight of rope put around the sheave on the sheave car, which is now at the west end. The car is pulled out to the east end and connected to the 300-ton testing machine. The end just coming off the reel is put into the gripper and clamped.

The socket on the rope is set so that its face is correctly positioned with respect to a previously determined line. The carriage is also set to a previously determined position. The jack attached to the gripper is pulled in until the tension in the strand, as recorded by the



Fig. 4—West End Building of the Prestressing Layout

In this building, measuring, cutting and socketing are done. The hydraulic jacks to which both ends of the rope are attached are near the door of this building.

jack is a hydraulic gripper which holds the unsocketed end of the rope during the period of stressing; on the bars of

weighing mechanism at the east end, is equal to the measuring tension. Then, by means of the testing machine at the east end, the tension is brought up to the value at which it is to be held for a given length of time. This tension is held by taking up on the 300-ton testing machine to compensate for the elastic and structural stretch of the rope under load.

At the end of the given time the carriage is let back to its correct position and the tension brought up to the measuring value by means of the gripper jack at the west end. The tension is then dropped well below the measuring value, by slacking off on the testing machine and immediately bringing it back to position. The tension is again corrected to the measuring value by the gripper jack, and the slacking off on the carriage is repeated. This procedure is followed until the tension in the rope is correct, and is necessary in order to equalize the tension in the rope at both jacks at the west end. The difference in tension at this end develops from the friction in the rollers on each side of the track, by which the two parts of rope are supported at 25-ft. intervals.

With the carriage at the east end and the socket at the west end, properly positioned, and the tension at the correct value, the strand is ready to be measured. The measuring tension is 80,000 lbs., as previously noted and the 36 ropes for the main span have calculated lengths from 3,556 ft. 2 in. to 3,557 ft. $6\frac{9}{16}$ in. For the New Jersey and New York side spans, respectively, the figures are 758 ft. 9 in. to 759 ft. $10\frac{3}{8}$ in. and 819 ft. $\frac{9}{16}$ in. to 820 ft. $5\frac{3}{4}$ in.

The differences in lengths of cables are plotted on a pair of rope scales so that when the scales are placed face to face the corresponding marks will coincide. Each scale is then fastened to a batter board, one board on each side of the track and outside of the rope position, at a point previously determined from an

accurate survey. The distance, then, from the socket position, in the south jack, running east to the carriage, around the carriage sheave, then west to the marking station where rope cables are mounted, is the length of the rope at the predetermined tension and the specified normal temperature.

In order to correct for temperatures different from the specified normal, temperature scales are graduated so that the distance between divisions represents the change in rope length per 1 deg. change in temperature. This scale is mounted on top of the rope scale with the normal temperature line coinciding with the line on the rope scale corresponding to the rope being measured. The zero marks on the temperature scales are toward the east, and the

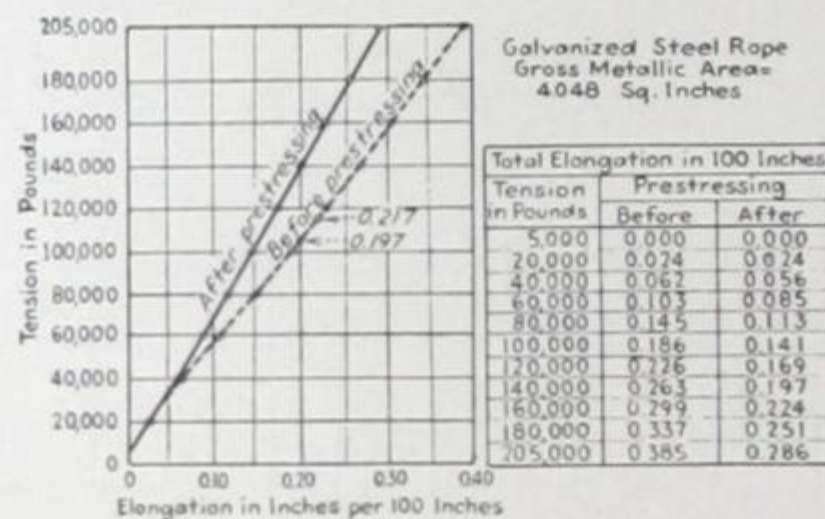


Fig. 6—Stress-Strain Diagram of a Foot-Bridge Rope before and after the Multiple Stressing

graduations are marked in degrees so that, with the temperature scales set for the proper rope number, the marking line is set at the prevailing temperature, as recorded at each end of the layout by precision thermometers.

A counterweighted line is stretched across the rope between batter boards and the rope is marked at the line. This mark represents the face of the socket, so the length of rope to be allowed for socketing is marked off from this line and the rope cut at the second mark. The piece of rope between the marking position and the gripper is the test sample.

When the rope is marked the tension

the distance, then, in the south to the carriage, heave, then west to where rope cables length of the rope and tension and the temperature.

For temperatures specified normal, are graduated so between divisions in rope length temperature. This top of the rope scale temperature line coincides on the rope scale rope being measured on the temperature the east, and the

Galvanized Steel Rope
Gross Metallic Area
4.048 Sq. Inches

Total Elongation in 100 Inches		
Tension in Pounds	Before Prestressing	After Prestressing
5,000	0.000	0.000
20,000	0.030	0.024
40,000	0.059	0.056
60,000	0.087	0.085
80,000	0.115	0.113
100,000	0.143	0.141
120,000	0.170	0.169
140,000	0.197	0.197
160,000	0.225	0.224
180,000	0.253	0.251
200,000	0.285	0.286

Diagram of a Foot-
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is dropped to zero, the carriage cut loose from the testing machine and the socket removed from the south jack. This socketed end is immediately put onto the reel and the reeling of the rope carried on while the rope is cut at the mark and the socket attached. The rope number is stenciled on each socket, as well as on the reel, thus giving complete identification before and after the rope is removed from the reel.

Along the eastern half of the layout and on the southern side of the track there are two buildings about 40 or 50 ft. away from the track. During most of the year, and especially during the months of November to April, when the sun is in the south, shadows are cast on the rope by these buildings. It is quite obvious then that the part of the rope in the shadow will have a temperature appreciably below the sun temperature. In fact, measurements of this difference in temperature have shown as much as 15 deg. F. during the winter months and 20 to 25 deg. F. in the summer months.

In addition to this a difference in temperature was found to exist between the top side of the rope, exposed to the sun, and the under side, which was out of the sun. It is readily appreciated that it is practically impossible to work out a temperature correction to length for the above conditions that would be accurate. Therefore it was necessary to make the measurements before sunrise, and as it required the remainder of that day to socket and reel the rope and prepare the next rope for prestressing, it permitted the rope to remain under the prestressing tension of 200,000 lbs. for about ten hours during the night. This long period of prestressing was an advantage in this particular case, for it assured uniformity of elastic stretch beyond the 160,000 lbs. tension and accomplished practically the same result as if the prestressing tension had been 250,000 lbs. for a short period of time.

The influence of prestressing is shown

by the stress-strain diagram of this rope (Fig. 6) before and after prestressing. The limitation of the manufacturing tension is quite evident.

Tests

The Port of New York Authority's specification for suspender rope required that two test pieces be taken from each set. There were performed in all 27 straight tension and elongation tests and 27 tests with two parts of rope

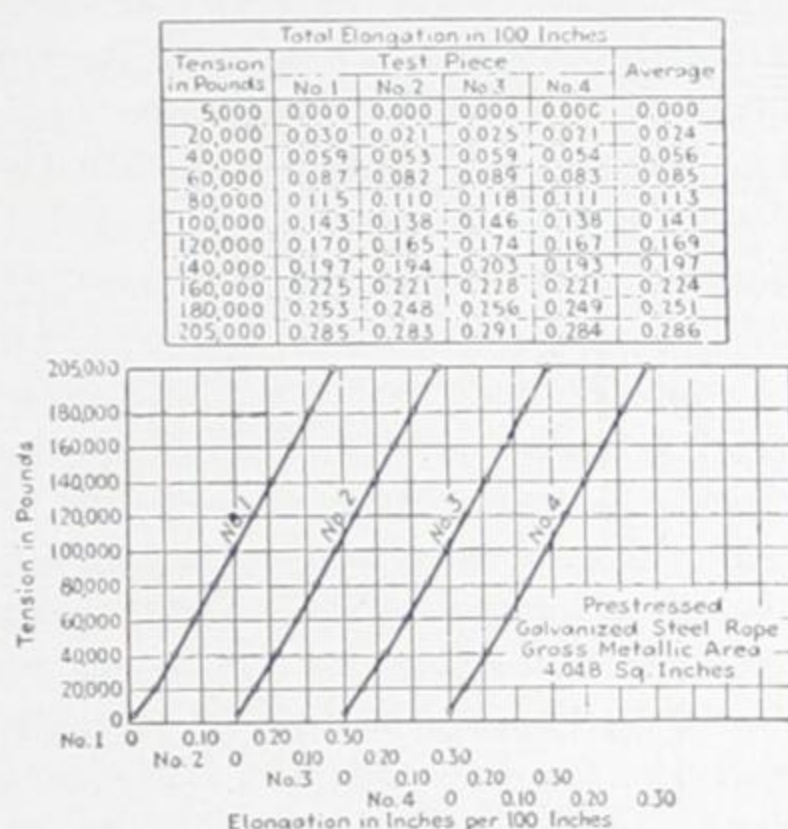


Fig. 7—Typical Stress-Strain Diagrams of Multiple-Stressed Rope for Hudson River Bridge Footbridge Cables

bent over a sheave (21-in. radius to the center line of rope). The typical stress-strain diagrams in Fig. 7 show the uniformity of the prestressed rope. Three of these ropes show a modulus of elasticity of 17,966,000 and the fourth, of 17,804,000 between 80,000-lbs. and 160,000 lbs. stress.

The average modulus of elasticity for the 27 tests of prestressed rope was 18,001,400 lbs. per sq. in. The average ultimate strength of the rope, based on 27 tests, was 780,000 lbs., the highest value being 797,000 lbs. and the lowest 734,000 lbs. With the exception of this one low value, the maximum variation from the average strength was 14,000 lbs. below and 17,000 lbs. above.

Based on the 27 tests of the rope

around a sheave of 42-in. diameter, an average strength of 1,335,800 lbs. was secured, or 85.6 per cent of the strength of the two parts of rope.

The calculations for the unloaded deflection of footbridge cables were based on the average modulus of elasticity of 18,000,000, and the cables were erected and adjusted to the calculated unloaded deflection. The loaded cable curve was found practically to conform to the required deflection, and after a period of five months under this loading, the ropes have maintained their original loaded deflection, indicating that the prestressing has removed the structural set within the range of the working tensions.

The $2\frac{15}{16}$ -in. galvanized ropes are 6x37 construction with an independent wire rope center, this center rope being equipped with a strand center, the entire cross-section being metallic. Considering that this cross-section is composed of 283 wires varying in diameter from 0.065 to 0.195 in., it will be appreciated that the uniformity of physical properties secured indicate both care and precision in fabrication.

We feel, however, that the prestressing must constitute the process of major benefit, for this big quantity of the largest diameter rope ever used for suspender ropes, shows greater uniformity of physical properties, higher efficiency of construction and higher efficiency when bent over a sheave, than any similar ropes within our experience.

The most recent use of this prestressing equipment has been in the manufacture of rope strands for the cables of the St. Johns bridge in Portland, Oregon, a structure with a 1,207 ft. main span.

In Fig. 8 is shown the beneficial effect

of multiple stressing on one of these $1\frac{1}{2}$ -in. strands, this particular one being the first experimental strand manufactured.

First Stress			Second Stress		
Total Elongation in 100 Inches			Total Elongation in 100 Inches		
Tension in Pounds	Application	Release	Tension in Pounds	Application	Release
32,600	0.000	0.157	32,600	0.000	0.152
40,000	0.021	0.179	40,000	0.020	0.173
60,000	0.080	0.218	60,000	0.079	0.235
80,000	0.142	0.298	80,000	0.135	0.294
100,000	0.205	0.355	100,000	0.193	0.354
120,000	0.273	0.413	120,000	0.250	0.413
140,000	0.345	0.470	140,000	0.309	0.471
160,000	0.424	0.528	160,000	0.369	0.530
180,000	0.514	0.585	180,000	0.430	0.588
200,000	0.622	0.641	200,000	0.494	0.646
205,000		0.647	220,000	0.605	0.704
			233,000		0.738

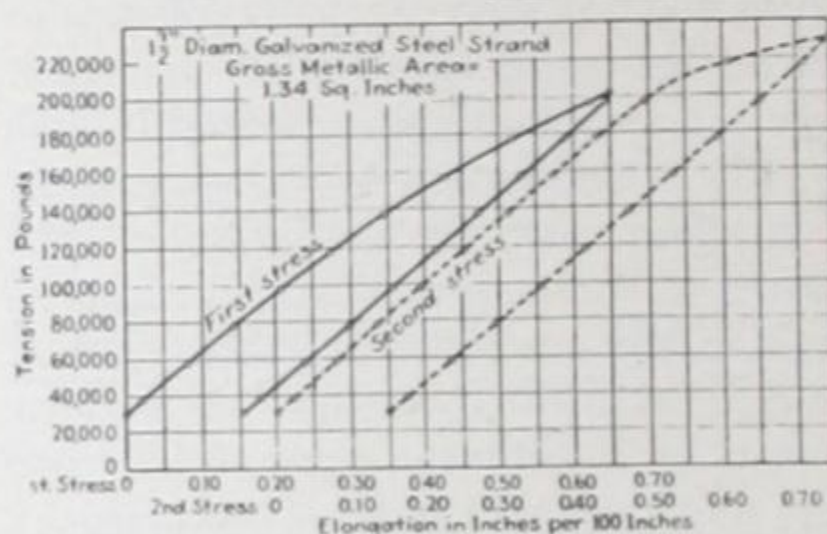


Fig. 8—The Effect of Multiple Stressing on an Experimental $1\frac{1}{2}$ -in. Strand for the Main Cables of the St. Johns Bridge

The structural stretch, being confined to wire placement instead of the complex wire placement and strand seating of the rope construction, results in a more uniformly changing curve on first stressing. Due to this advantage, the prestressed strand will, of course, show a much higher modulus of elasticity than the rope construction. With proper fabricating machinery and prestressing the strand, a strand modulus of elasticity can be secured equal to 88 per cent of the wire modulus.

The work above described is part of the contract of the John A. Roebling's Sons Company for the furnishing and erection of the wire cables for the Hudson River bridge, now being built by the Port of New York Authority.

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The Rope-Strand Suspension Bridge at Grand' Mere, Quebec

Structure of 949-Ft. Main Span is Longest of Type Yet Built—
Cable Ropes Cut to Length and Socketed in Shop—
Unusual Erection on Ice of St. Maurice River

By D. B. STEINMAN

Consulting Engineer, New York City

Reprinted from ENGINEERING NEWS-RECORD, November 28, 1929

THE new highway toll suspension bridge over the St. Maurice River at Grand' Mere, Quebec, with a main span of 949 ft. is believed to be the first large suspension bridge in Canada and the longest rope-strand cable bridge in the world. A number of other novel features characterize both the design and the erection of the structure.

The use of rope-strand cables is unique in a structure of such long span. In addition to this, a special bridge floor of laminated redwood covered with an asphalt wearing surface is used; the end bearings of the stiffening trusses are seated directly on the main pier inside the main tower legs; and flat plates instead of eyebars are used in the anchorages.

Steel and cable erection was commenced and completed in the winter season, the freezing of the river governing the choice of erection methods. In spite of the rigors of the northern climate, new erection speed records were established.

A demand for a bridge at this point was foreseen by the management of a local paper mill, the Laurentide Company, when in 1913 it began a hydro-electric development below the present bridge site, which would raise the water level of the river about 35 ft. Because of this depth of water and the soft nature of the riverbed, it was decided

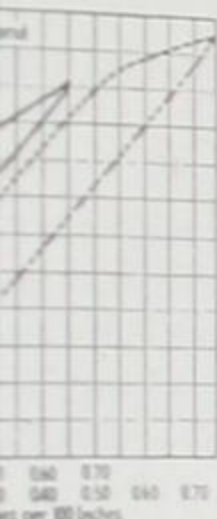
that a suspension bridge would be most practicable, and in order to avoid additional expense later, the main piers were built at that time for a bridge with fixed-base towers.

Also in order to facilitate the passing of pulpwood logs to its paper mill, the Laurentide Company constructed in 1917 the approach span of 155 ft. between the west pier of the main bridge and the west bank of the river. In 1927 the city authorities decided to go ahead with the completion of the bridge, and designs were made and bids submitted on a cantilever structure with concrete roadway for two lines of 20-ton trucks. The lowest bids obtained were considerably in excess of \$500,000, and this project finally was abandoned in favor of the present design.

The Grand' Mere bridge is a stiffened suspension structure with straight backstays. Its principal dimensions and details are shown in Fig. 2, page 44. An 18-ft. roadway is provided, consisting of laminated redwood with a normal thickness of 6 in., laid with $\frac{1}{2}$ -in. crown and covered with $1\frac{3}{4}$ in. of asphalt. Sidewalks on either side consist of $2\frac{3}{4}$ -in. creosoted fir, covered with a brush coat of hot asphalt and a sprinkling of fine-screened gravel. The stiffening trusses were shipped in two-panel lengths, 24 ft. 4 in. long. A half-through section was

on one of these
particular one
experimental strand

Second Stress	Initial Elongation in 100 inches
Strands	Applied Release
12,000	0.000 0.151
40,000	0.020 0.173
80,000	0.070 0.235
120,000	0.135 0.294
160,000	0.252 0.354
200,000	0.415 0.415
240,000	0.750 0.471
280,000	0.309 0.530
320,000	0.430 0.588
360,000	0.494 0.646
400,000	0.605 0.704
440,000	0.773



Multiple Stressing on
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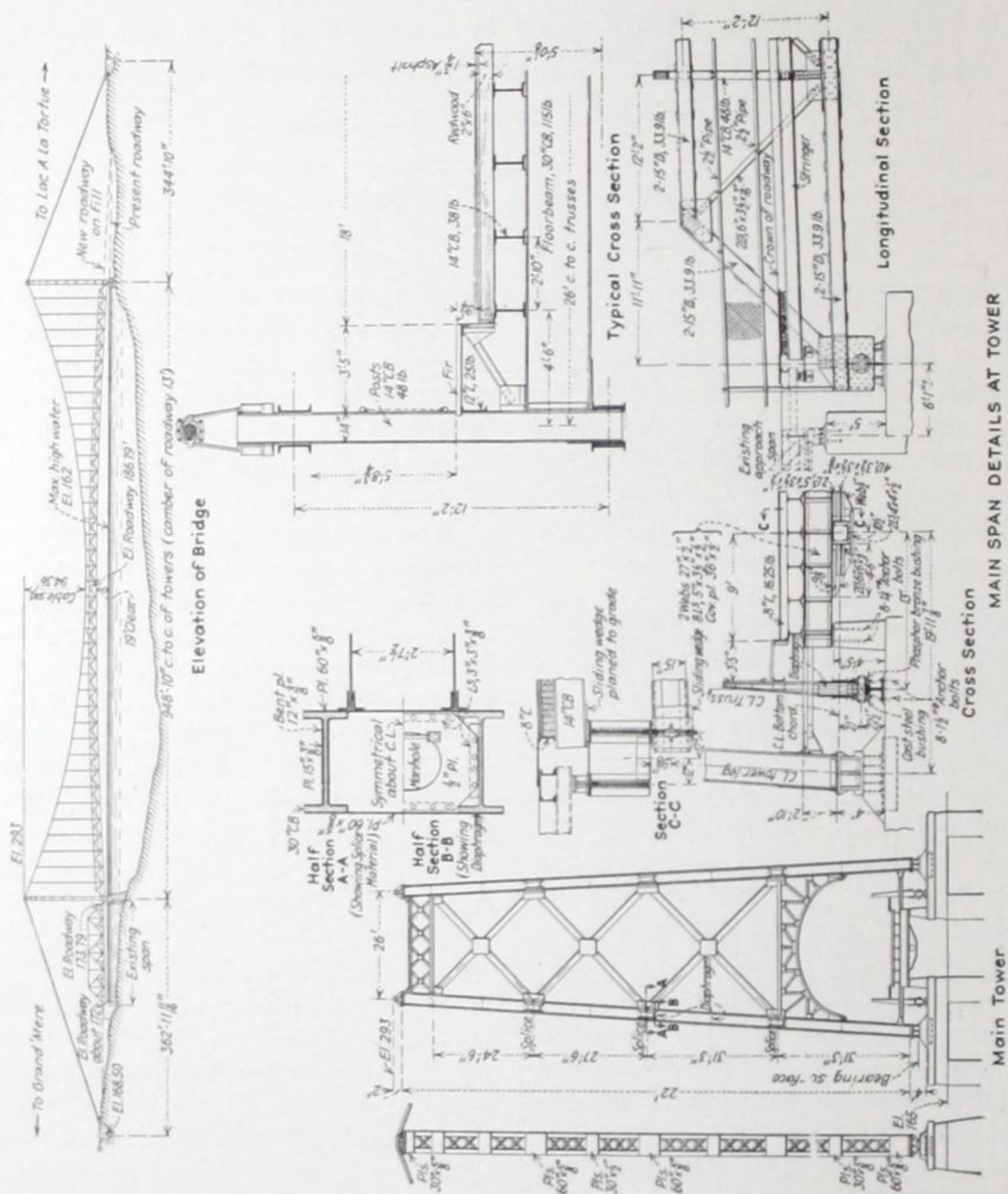


Fig. 2—Details of Long Span Rope-Strand Cable Suspension Bridge

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The end-beams are supported by vertical trusses, designed to resist the load while resisting the load directly on the beams. The expansion beams are supported by a square pin, with a diameter, sliding in a phosphor bronze bearing with a circular slot in the end. Medium-strength steel is used throughout the

Desi

The floor is a standard low-bed trailer for 15-ton trucks. The floor is stiffened by a transverse stiffening truss supporting a loading of 60,000 lb. per sq. ft. covering the entire floor area in accordance with the loading of the American Institute of Steel Construction. The structure is designed to stand a wind load of 100 lb. per sq. ft. on unloaded side and end respectively, and a temperature of 800° F. for a range of 80° F. The structure is designed for a live load of 2,430 lbs. and a dead load of 1,152 lbs. per sq. ft.

Cables

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The end-bearings of the stiffening trusses, designed to permit expansion while resisting possible uplift, are seated directly on the tops of the main piers. The expansion bearing consists of a 6-in. square pin, with ends turned to $5\frac{3}{4}$ -in. diameter, sliding between lubricated phosphor bronze bushings in a rectangular slot in the cast-steel bearing pedestal. Medium-carbon steel is used throughout the structure.

Design Loading

The floor system is designed for a standard loading of two lines of 15-ton trucks. The cables and the stiffening trusses are proportioned for a loading of 60 lbs. per sq. ft. covering the entire roadway and 12 lbs. per sq. ft. covering the sidewalks, in accordance with the specified U-80 loading of the Canadian Engineering Standards Association. In addition, the structure is proportioned to withstand a wind load of 35 and 25 lbs. per sq. ft. on unloaded and loaded spans respectively, and temperature stresses for a range of 80 deg. F. from a normal temperature of 40 deg. F. The cables are designed for a total dead load of 2,430 lbs. and a specified live load of 1,152 lbs. per linear foot of bridge.

Cables and Suspenders

Each of the two main cables contains 37 galvanized steel strands $1\frac{1}{4}$ in. in diameter, each strand made up of 35 acid open-hearth steel wires as follows: center wire, 0.192 in. diameter, followed by six wires 0.182 in. diameter, six wires 0.148 in. diameter, six wires 0.197 in. diameter and sixteen wires 0.195 in. diameter. The total sectional area is 0.9559 sq. in. and the weight per foot is 3.38 lbs.

When the strands were measured under specified tension (20,000 lbs.) for

cutting to length, they were marked at calculated points corresponding to tower centers and span center. Two strands for each cable also were marked at the cable band centers, these marks to serve as guides in placing the bands. Special sockets were placed on the strands before shipment.

The specified tolerance in length variation was $\frac{1}{2}$ in., and variations in length were adjusted by placing shims in front of the socket bearings. The application of the method of using galvanized bridge strands cut to a specified length when measured under tension, in connection with a special design of anchorage assembly, was developed by the John A. Roebling's Sons Company, Trenton, New Jersey.

The minimum ultimate strength for each strand was specified at 180,000 lbs. and showed 199,000 lbs. in tests. The minimum guaranteed modulus of elasticity for the strands was specified at 21,000,000 lbs. per sq. in.; tests yielded values exceeding 25,000,000 and the design computations were based on a modulus of 24,000,000.

The $1\frac{1}{4}$ -in. diameter galvanized steel suspender ropes are made up of six strands of seven wires each placed around an independent wire rope center. Each of the strands has a center wire 0.139 in. in diameter surrounded by six wires 0.137 in. in diameter. The independent wire rope center has a center strand composed of seven wires of 0.056-in. diameter surrounded by six outer strands each consisting of a center wire 0.054 in. in diameter and six outer wires 0.051 in. in diameter.

Main Towers

The main towers are of the rocker type, each tower leg being made up of two 30-in. rolled beams connected with double lacing and tie plates and stiffened with transverse diaphragms. The tower sections were completely assembled in the shop, the

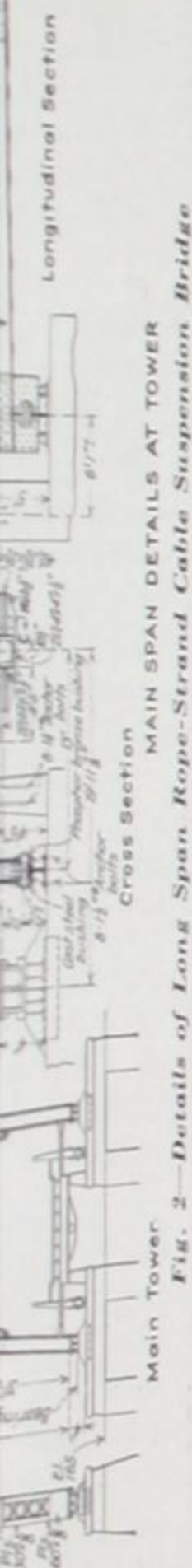


Fig. 2—Details of Long Span Rope-Strand Cable Suspension Bridge

holes for field connections reamed to metal templates and the connecting parts match-marked before shipment to the bridge site. The towers were erected leaning about 18 in. toward the anchorages.

Anchorages and Strand Assembly

The cables are anchored into the solid rock on each side of the river by a

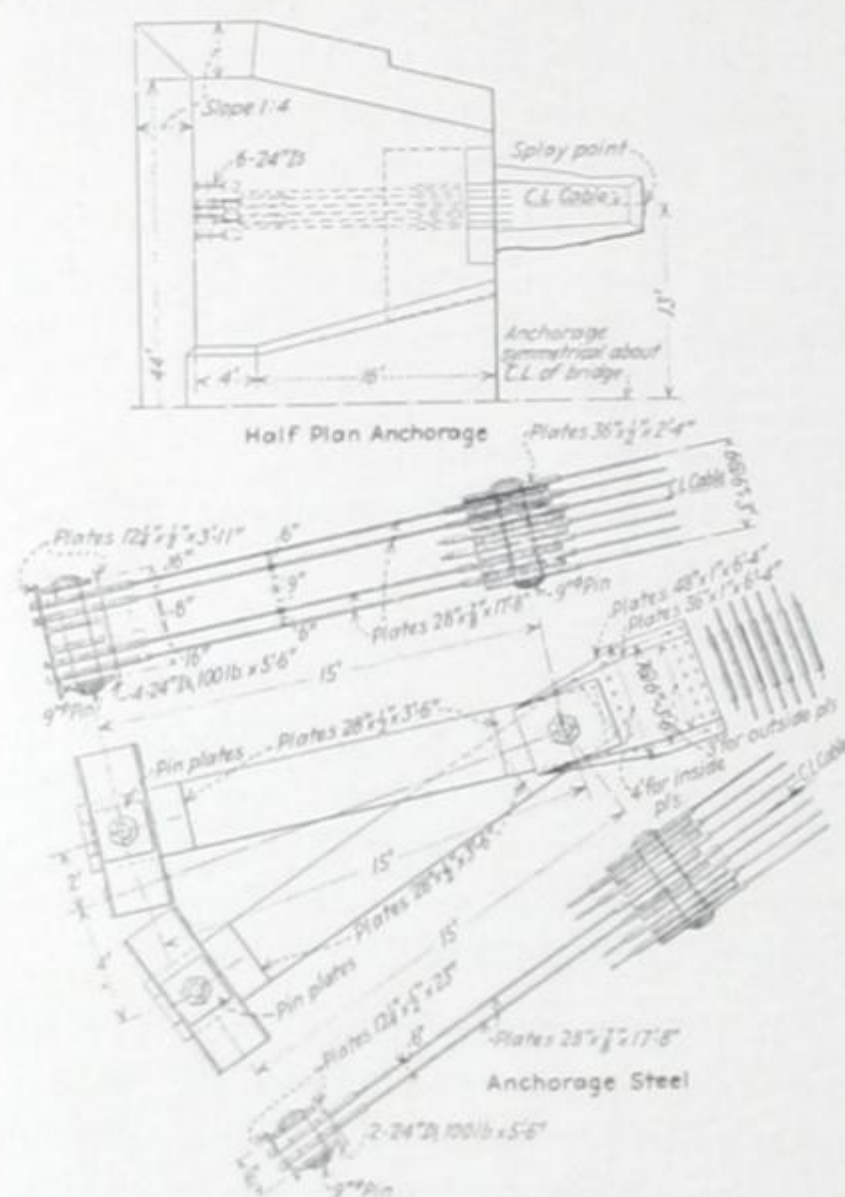


Fig. 3—Anchorage Details, Grand' Mere Bridge

system of plates connected to steel grillages embedded in concrete. There are 500 cu. yds. of concrete in each anchorage, exclusive of the exterior concrete housing placed after the cables and span were completed. For additional security, the concrete in each anchorage is anchored to bedrock with twenty 2-in. fox-bolted steel dowel rods, 20 ft. long.

As shown in Fig. 3, six 28x $\frac{7}{8}$ -in. plates connect the Y-point of the anchorage steel to the anchor grillages. At the Y-point a 9-in. pin holds a nest of seven vertical anchor plates, 1 in. thick and 6 ft. 4 in. long, each reinforced with two $\frac{1}{2}$ -in. pin plates; the five inner

plates are 48 in. wide and the two outer plates are 36 in. wide.



Fig. 4—Floor of Laminated Redwood Previous to Placing Asphalt Wearing Surface, Grand' Mere Bridge

The special bearing block steel castings are secured between these anchor plates by means of sixteen $1\frac{1}{16}$ -in. diameter bolts; twelve of these in each assembly go through all seven anchor plates, whereas the four others pass through only the five wider plates. The bearing blocks between

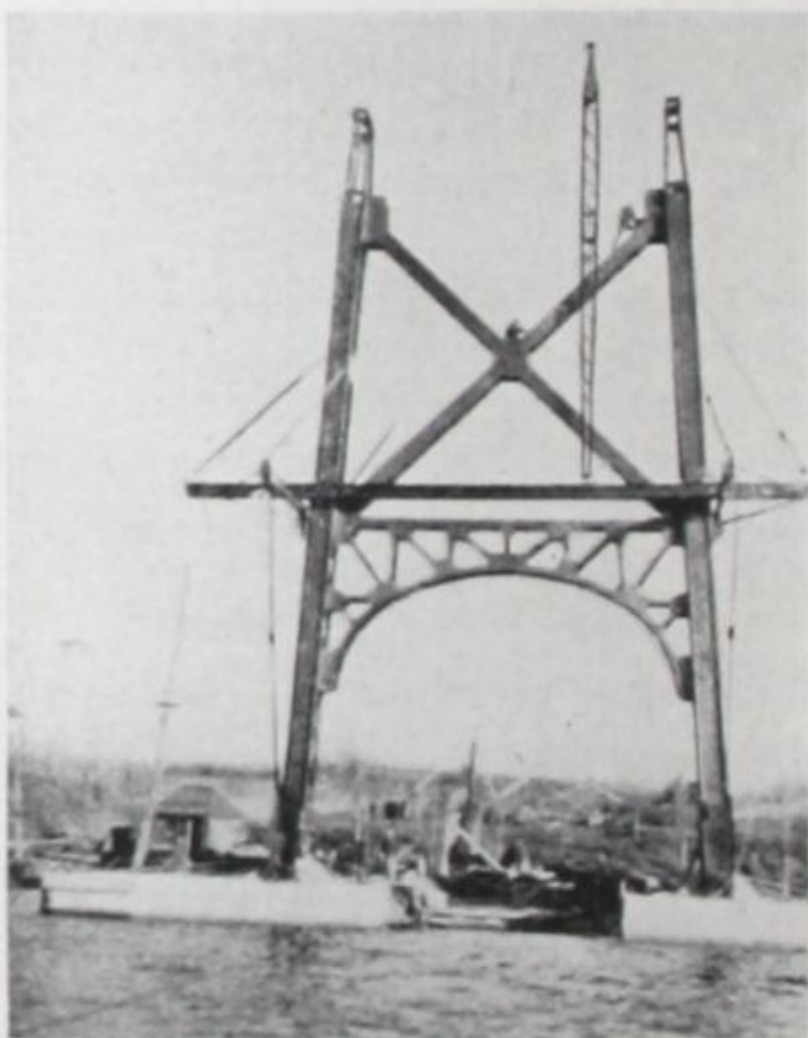


Fig. 5—Jumpingjack Creeper Erecting Tower of Grand' Mere Bridge

Headframes on top of tower legs used to hoist creeper.

the plates have bell-mouthed semi-circular grooves top and bottom between which the $1\frac{1}{4}$ -in cable strands

are held by the U-shaped shims



Fig. 6—Rope-Strand

One strand on either side of the tower legs was strung along the tower legs. The procedure was to string the strand in the anchorage and then to pull it up to the top of the tower.

sockets and the adjustment of struts.

Erection of

Erection of involved interest



The truss steel in attached near susp

are held by the abutting strand sockets. U-shaped shims are placed between the



Fig. 6—Rope-Strand Cable Erection, Grand' Mere Bridge

One strand on either cable in place. Remaining strands strung along wooden horses on ice. Erection procedure was to engage the socket of a strand in the anchorage and lift it to the saddles by means of falls from the top of the towers.

sockets and the bearing blocks for adjustment of strand lengths.

Erection Methods

Erection of the Grand' Mere bridge involved interesting methods, not only

because of the use of rope-strand cables but also because of the extraordinary climatic conditions prevalent during the period of erection. Practically all of the major construction operations were carried on during November, December, January and February. While in many respects the weather retarded progress of the work, in other ways it expedited the erection, for the freezing of the river with a 24- to 30-in. layer of ice, was the governing factor in the choice of cable and truss erection methods.

The main towers of the bridge were shipped to the site almost entirely dismantled, so that the heaviest piece, the portal strut, weighed only 5 tons. The lightness of the members permitted the use of a light creeper traveler, or jumpingjack consisting essentially of a steel ginpole guyed to a steel frame which was hoisted up the tower as the erection progressed. Three jumps of the traveler were necessary to complete the erection, including the placing of the cast-steel saddles. The towers, of the rocker type, had to be tied to the piers during construction, and as the tower grew in height further stability was assured by the use of timber struts and wire rope guys.

When completely erected, the towers



Fig. 7—Lifting the Stiffening Trusses into Position

The truss steel in two-panel lengths delivered on sleighs from railroad yards to location in bridge. Falls attached near suspender points hoisted the truss sections into place.

were leaned back the theoretical amount required by the unloaded cable calculations, and the first two strands, one in each cable, were hoisted into place, adjusted to marks on the tower saddles and their positions checked with the transit.

Theoretically the 37 strands in each cable were of 30 different lengths. For cutting purposes the strands were modified so as to make a smaller number of different lengths. Each strand, about 1,680 ft. long, was shipped on a reel which was placed in a frame at the west end of the bridge. As the strand was unreeled, the free end was hauled across the ice by a line from an electric winch located at the east anchorage, the strands being kept free of the ice by wooden horses about 6 ft. high spaced about 30 ft. apart.

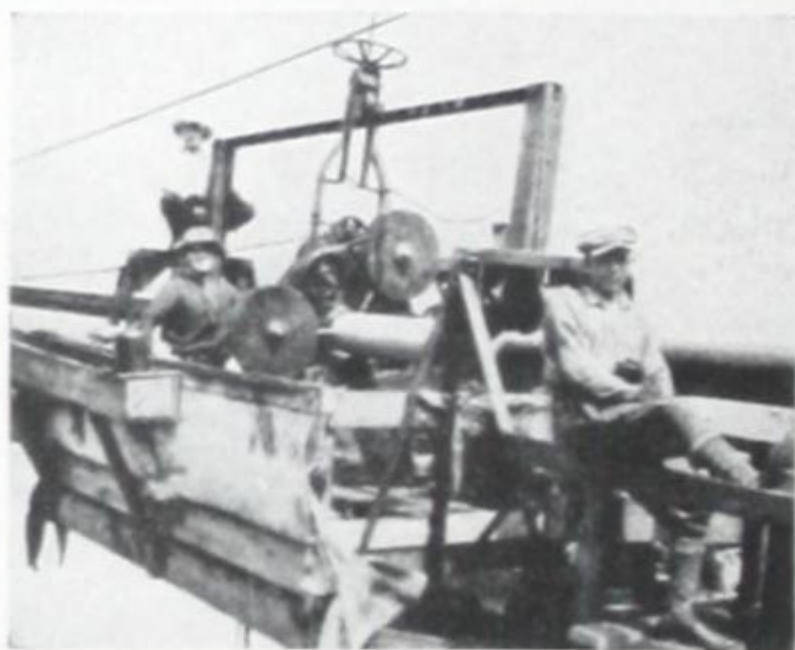


Fig. 8—Cable-Wrapping Machine in Operation on Grand Mere Bridge

After the strands were thus laid out, the sockets were fastened to the anchorage connections and the strands, one at a time, were then wired to a balance beam at each tower and hoisted to their position in the saddles by sets of falls hung from A-frames on the tops of the towers. The first strand in each cable was the guide strand, all of the others being adjusted to it. Above the main cable there was strung a $\frac{7}{8}$ -in. diameter carrier cable along which were run the cages and chains used in adjusting the strands,

placing the cable bands and suspenders, and finally painting the cables.

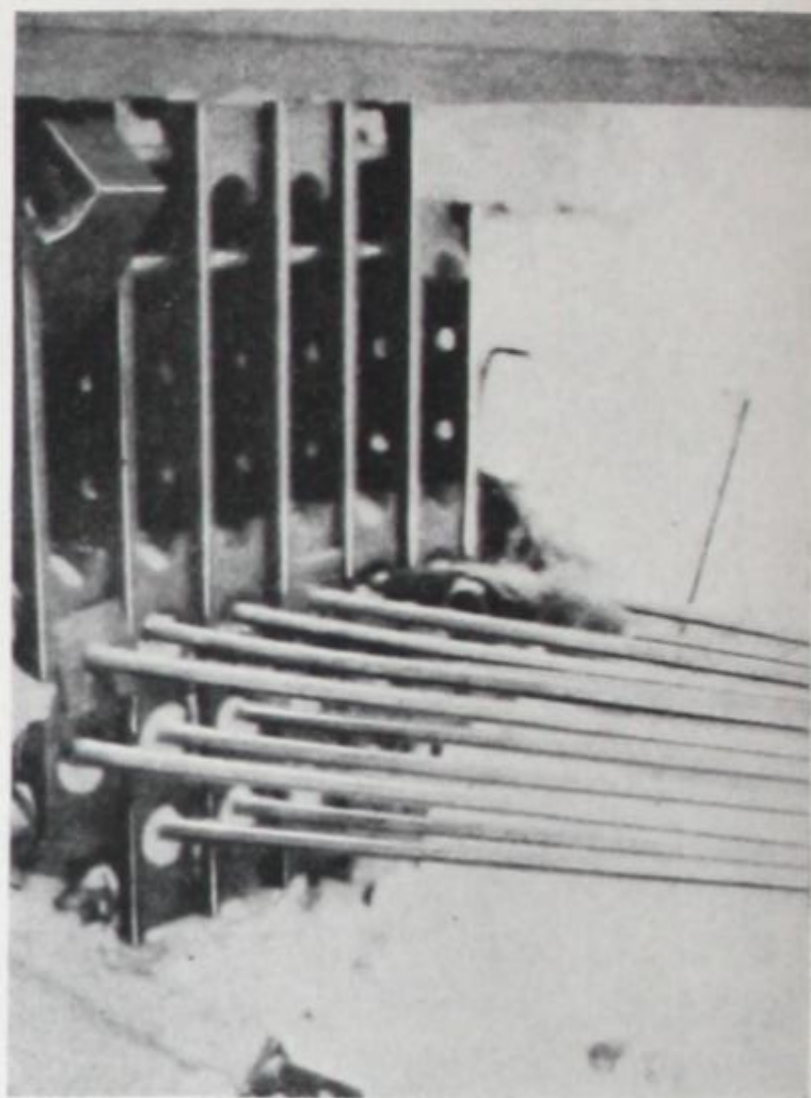


Fig. 9—Connection of Rope Strands to Anchorage Steel

The truss sections were shipped to the site in two-panel lengths, varying in weight from 7 to 10 tons. Each section was placed on a sleigh at the railroad yard and pulled by horses on the ice to its proper position in the span. It was then fastened to two sets of falls, hanging from the cable, one near each point of suspender connection. Each set of falls had an independent lead line running through a snatch block, which was fastened by a wire rope loop to a deadman under the ice to a double drum engine located at the main tower. There were two such layouts, permitting symmetrical truss erection from the center of the main span toward the towers. Completion of the erection followed usual methods.

Cable Wrapping

In order to fill out the hexagonal section of the assembly of 37 strands into a circular section, segmental redwood strips, $\frac{1}{2}$ in. thick, were

placed immediately after the application of the first coat of boiling linseed oil. These redwood strips, after the final cable wrapping, continuous serving, double galvanizing, and wrapping, the suspender ropes and given one coat of finish coats of the light green steelwork.

On May 4, 1911, the structure was subjected to a deflection test, weighing 22 tons, a calculated deflection under a concentrated load of 22 tons. The measured deflection was 1.5 ft., a full measurement. In the morning, when the under side of the midspan to be in elevation.

Engineering

The Grand' by Robinson and engineers, New York, constructed under

placed immediately in advance of the application of the wrapping wire. These redwood strips were soaked in boiling linseed oil before placing. The final cable wrapping consisted of a continuous serving of No. 9 soft-annealed double galvanized steel wire. After wrapping, the cables, cable bands, suspender ropes and all attachments were given one coat of red-lead paint and two finish coats of lead paint tinted to match the light green color of the structural steelwork.

Load Tests

On May 4, 1929, the completed structure was subjected to a load-deflection test by placing two trucks weighing 22 tons at midspan. The calculated deflection for this concentrated loading was $3\frac{7}{16}$ in. and the measured deflection was $3\frac{1}{16}$ in. Careful measurement taken in the early morning, when there was no sun, showed the under sides of both top chords at midspan to be within $\frac{1}{16}$ in. of each other in elevation.

Engineering and Construction

The Grand' Mere bridge was designed by Robinson and Steinman, consulting engineers, New York City, and was constructed under their direction. They

were retained with the approval of the Province, the City and the Laurentide Company, by Fraser-Brace, Ltd., of Montreal, which concern built the bridge under a lump sum contract. The work was subject to the official approval of Ivan E. Vallee, chief engineer of the Department of Public Works of the Province of Quebec, Canada. P. L. Pratley, of Monsarrat & Pratley, consulting engineers, Montreal, represented the City and the Province in reviewing the design and construction. E. B. Wardle, chief engineer of the Laurentide Company, was appointed supervising engineer of the project, and J. A. Bernier, city manager of Grand'Mere, was named as his assistant. L. G. Cox was local superintendent for Fraser-Brace, Ltd., R. Boblow, who prepared the erection sections of this article, was resident engineer for Robinson & Steinman.

The lump sum fee paid to Fraser-Brace, Ltd., for the construction of the bridge was \$375,000. The project was financed by the City by means of bonds guaranteed by the Provincial government, which also agreed to be responsible for one-half of the annual deficit if any, including provision for sinking fund, the City being responsible for the balance.

Rope-Strand Cables Used in New Bridge at Portland, Oregon

St. Johns Bridge, With a 1,207-Ft. Suspended Span over Willamette River, Sets New Record for Rope-Strand Cables —Extensive Architectural Studies Result in Use of Unique Batter-Leg Towers in Which Pointed Arches Accentuate the Pleasing Appearance

BY D. B. STEINMAN

Robinson and Steinman, Consulting Engineers, New York City

Reprinted from ENGINEERING NEWS-RECORD, February 13, 1930

NOTABLE innovations in suspension bridge practice have been incorporated in the design of the St. Johns bridge, over the Willamette River at Portland, Oregon. With a main suspended span of 1,207 ft., it represents the longest bridge upon which rope strand cables have yet been used, and at the same time it is the longest suspension structure of any type west of Detroit. An underclearance of 205 ft. above navigable water, constitutes an additional record.

Unusually complete architectural studies accompanied its design. The use of batterleg towers, presenting a pleasing appearance by virtue of the elimination of the conventional diagonal bracing and the use of pointed arch outlines above and below the roadway are features worthy of note. This same motif of pointed arches is extended to the main masonry piers and to the approach piers, where the vaulted opening in the tallest of these piers exceeds a height of 150 ft. Duplication of truss span lengths in the approaches, combining the masonry of the anchorages with the masonry of the adjacent approach span piers, and the use of a special anchorage layout in which silicon steel plates form the anchor chains, are other features of the structure.

The bridge was built by Multnomah County to span the Willamette River between two sections of Portland—the St. Johns district on the east bank and the Linnton district on the west bank. Seven bridges now span the Willamette at Portland; the St. Johns bridge is the most northerly crossing and nearest the point where the river flows into the Columbia River. The new bridge affords a connection between the Upper Columbia River Highway east of Portland and the Lower Columbia River Highway from Portland to Astoria.

Alternative designs and estimates for cantilever and suspension designs, respectively, at four different locations were prepared. The comparative estimates revealed a saving of \$640,000 by using a suspension design at the adopted location, a saving which would permit the capacity of the structure to be increased from three to four lanes. In addition a large balance of the authorized appropriation would be left unexpended. This suspension design was finally adopted.

In the St. Johns bridge, the desire to secure a beautiful public structure was a governing consideration. The selection of the suspension type, with its naturally graceful cable curves, was the

first step in development of steel towers, that would eliminate of the adoption of dominant mo architecture al design of the of the viaduct Special desi balustrades, th other details monize with t of the abutme

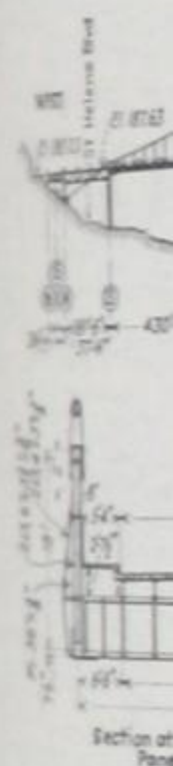


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first step in that direction. The development of the design of the high steel towers, to secure outlines in steel that would express the harmonious combination of beauty and strength, led to the adoption of pointed arches as the dominant motif, and this style of architecture also was carried out in the design of the tall reinforced-concrete of the viaduct approach.

Special designs for the ornamental balustrades, the lighting standards and other details were developed to harmonize with the main towers. Details of the abutment pylons and parapets,

establish a new mark in artistic bridge design.

Principal Dimensions

The main span of the St. Johns bridge clears the harbor lines with a length of 1,207 ft. center to center of main piers and is flanked by two suspended side spans each 430 ft. 3 in. long. The cable sag is 120.7 ft., one-tenth of the span. In order to meet navigation requirements established by the port of Portland, the underclearance is 205 ft. at the center of the main span.

The east viaduct consists of two

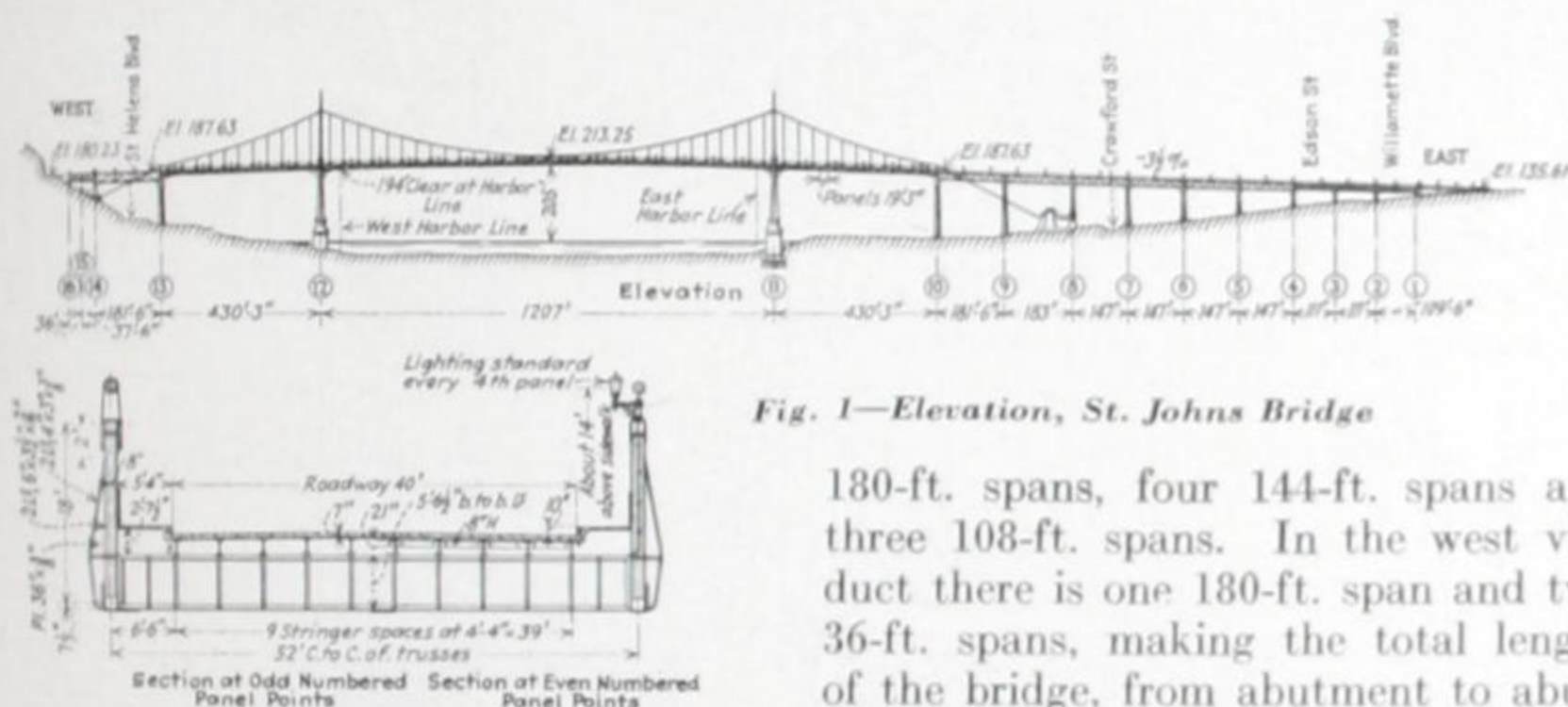


Fig. 1—Elevation, St. Johns Bridge

180-ft. spans, four 144-ft. spans and three 108-ft. spans. In the west viaduct there is one 180-ft. span and two 36-ft. spans, making the total length of the bridge, from abutment to abutment, 3,606½ feet. A U-type east abutment carrying concrete roadway on fill, adds 227 ft. more to the length of the construction. The west abutment marks the junction with the west approach, which involves about 1 mile of side hill road construction. Accordingly the work embraces about 4,000 ft. of bridge construction and 5,000 ft. of approach road construction.

Foundations

Preliminary wash borings, made at the four different locations, contemplated for the proposed bridge, formed the basis for preliminary designs and comparative estimates. After the site was selected, final confirmatory core borings were made at the locations of the piers and anchorages. On the east bank the borings revealed only

the viaduct piers, the massive main piers and the anchorages were modeled to the graceful curves and contrasting reliefs of the governing style.

A special attempt was made to develop each material in a manner appropriate to its accepted characteristics. It is sincerely hoped by the designers that the St. Johns Bridge, by virtue of the substitution of buttressed columns and arched outlines for the conventional utilitarian X-bracing, of the gracefulness and rhythm of its approach spans supported on an arcade of concrete piers of ascending height, and of the harmonious development of the architectural features in an attempt to present a pleasing and impressive view of the structure from all possible angles, will

Fig. 2—Panel Points.

layers of clay and sand, which necessitated a substructure design with spread footings and with pile foundations under a number of piers. On the

west bank the borings showed rock at El.—11 to —23 for the west main pier, and rock under 4 to 8 ft. of clay for the viaduct piers.

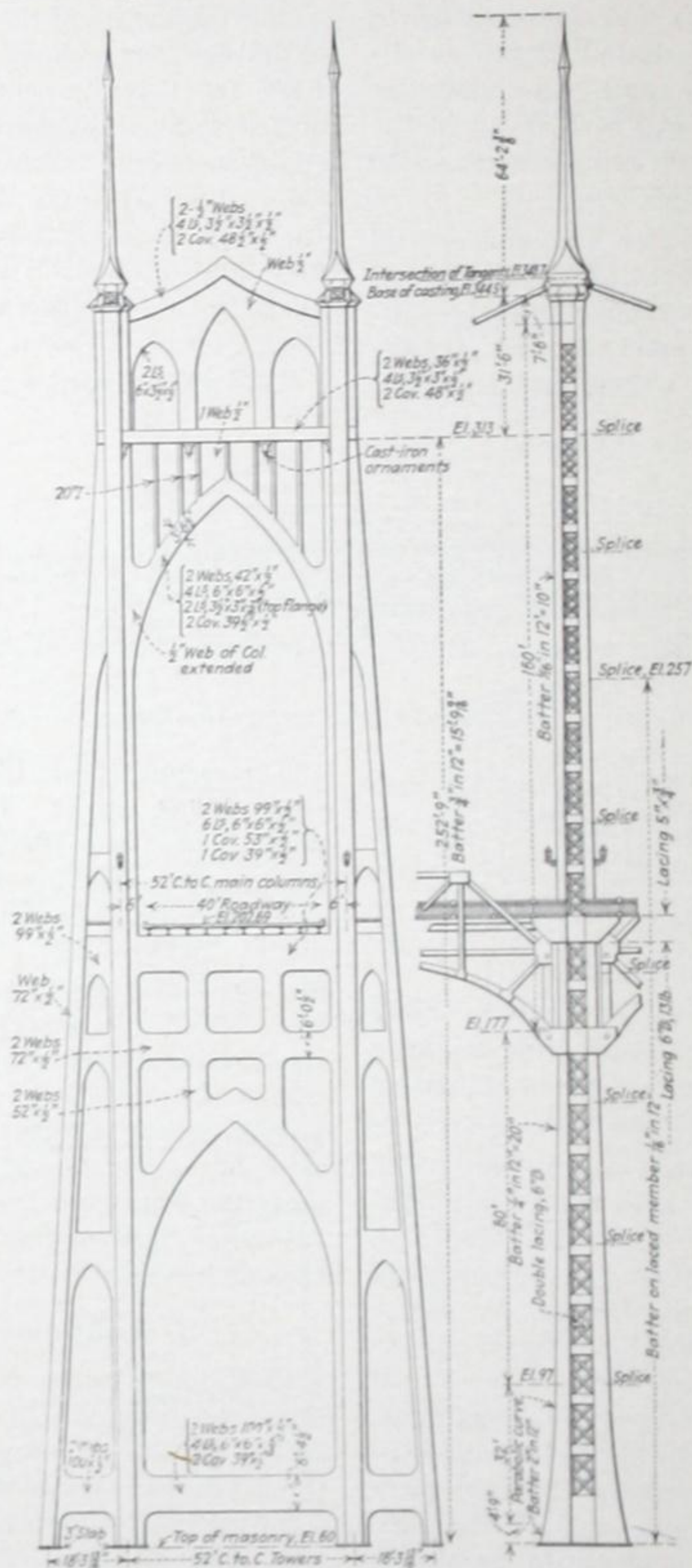
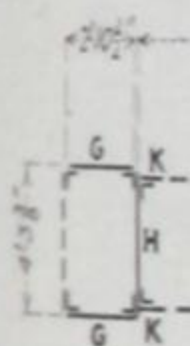


Fig. 3—Batter-Leg Main Towers on St. Johns Bridge

Vertical leg for direct loads and batter-legs in lieu of diagonal bracing combined with pointed arch portal outlines, are distinguishing factors in architectural design of the bridge.

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Main

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B 45 1/2"
C 45 1/2"
G 34 1/2"
H 34 1/2"
K 27 1/2"
L 27 1/2"
M 27 1/2"

Angles - All main

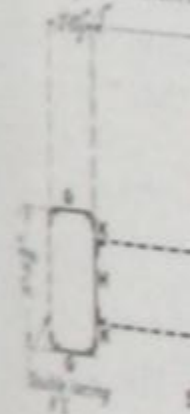
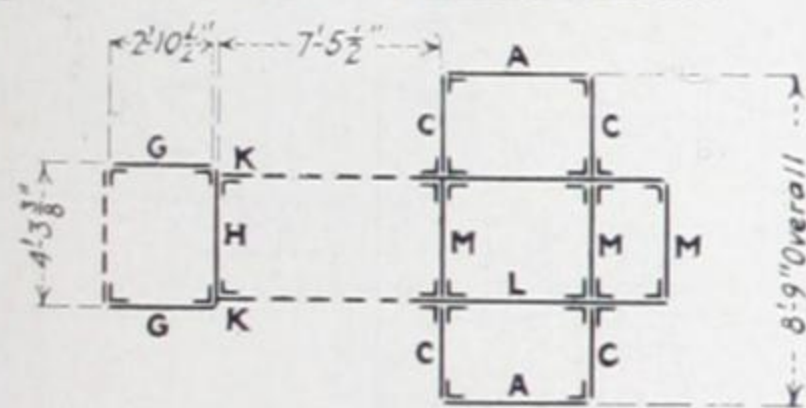


Fig. 4—S

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All piers are of reinforced concrete. The east main pier has its foundation at El. -50, on wood piles driven under water into hard sand. It contains 17,000 cu. yds. of reinforced concrete and in order to reduce its weight, 72-in. wood stave pipes are placed vertically in the body of the pier so as to leave hollow cylindrical shafts. The west main pier is founded on rock at El. -25.

The shafts of the viaduct piers are of tapering cruciform section, connected at the top with pointed arches. These piers ascend in height reaching El. +160 at pier No. 10. It is believed that this pier, 163 ft. from top to bottom and containing 3,700 cu. yds. of concrete and 150 tons of reinforcing steel, is the largest reinforced-concrete rigid-frame pier yet constructed. The piers are reinforced with structural steel frames supplemented with rod reinforcement.



Section at El. 177

Main Tower Section

- Webs - A $46\frac{1}{2} \times 1\frac{1}{4}$
 B $46\frac{1}{2} \times 1$
 C 1" tapered
 G $34 \times \frac{3}{8}$ below El. 257
 H 1" tapered
 K $12 \times \frac{1}{2}$
 L 84×1 (extended at struts)
 M 39×1

Angles - All main $2\frac{1}{2} \times 6 \times \frac{1}{2}$ except as noted

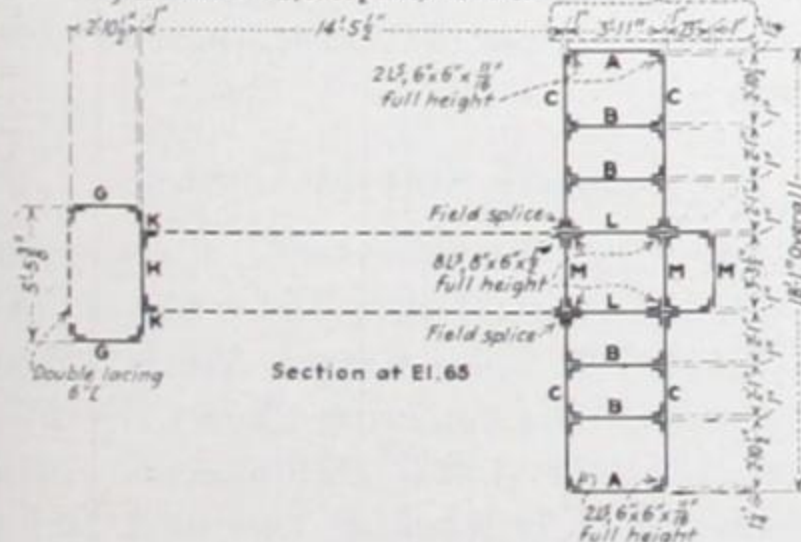


Fig. 4—Sections of Main Tower

The east anchorage is 115 ft. long, 91 ft. wide and extends from El. + 12 to + 82. It contains 13,000 cu. yds. of

concrete. In addition there are hollow chambers filled with sand, to provide a total weight of 30,000 tons. A stepped foundation on a spread footing is used with pedestal concrete piles to provide additional horizontal and vertical resistance. About half of these piles are battered.

The west anchorage is in a tunnel cut from the solid rock. It is surmounted by an exterior structure supporting viaduct piers Nos. 14 and 15.

The anchorage steel is shown in Fig. 7, page 55. The anchor chains, connecting to the anchor girders, are formed of plates of silicon steel, with reinforcing pin-plates, as a substitute for the usual eyebar construction.

Main Towers and Cable Bents

The main towers comprising one of the unusual features of the structure, are of medium-carbon steel, of the semi-flexible type, fixed at the base. Each tower consists of two main vertical columns, 52 ft. center to center, supplemented by outside batter-legs. The combination of vertical legs for direct load with batter-legs for bracing, produces a highly satisfying solution of the esthetic problem of tower design for suspension bridges. The effectiveness of the pointed arches in the towers of the Mount Hope bridge, near Providence, R. I., prompted the adoption and further development of this motif in the design of the St. Johns bridge, where similar arches are utilized both above and below the roadway as shown in Figs. 1 and 3.

The tower legs are of cruciform section, with box divisions. The main column section tapers from a width of 18 ft. at the base to 7 ft. 4 in. under the saddles, with a constant breadth of 4 ft. 1 in. The total height of the towers, including the finials, is 408.7 ft. above mean low water.

Following the mathematical analysis of the deflections and stresses in the

main towers, check tests were made on an elastic model, built up sheets of celluloid to represent the variations of cross-section and moments of inertia. Scale forces were applied to represent the simultaneous action of maximum vertical and transverse loads on the tower, precision strain gauges being used to read the stresses. This work was done by the engineering staff for the bridge under the supervision of Prof. George E. Beggs, in the engineering laboratory at Princeton University.

combination of loadings to which it might be subjected.

The cable bents are of the rocker type, but are provided with wing plates at the base to hold them during erection, these plates to be burned off after the cables are in place. The connection between the cable bent columns and the side span stiffening trusses is made by means of 6-in. pins in lubricated bronze bushings. A transverse truss in the cable bent supports the roller bearings for the 180 ft. approach span

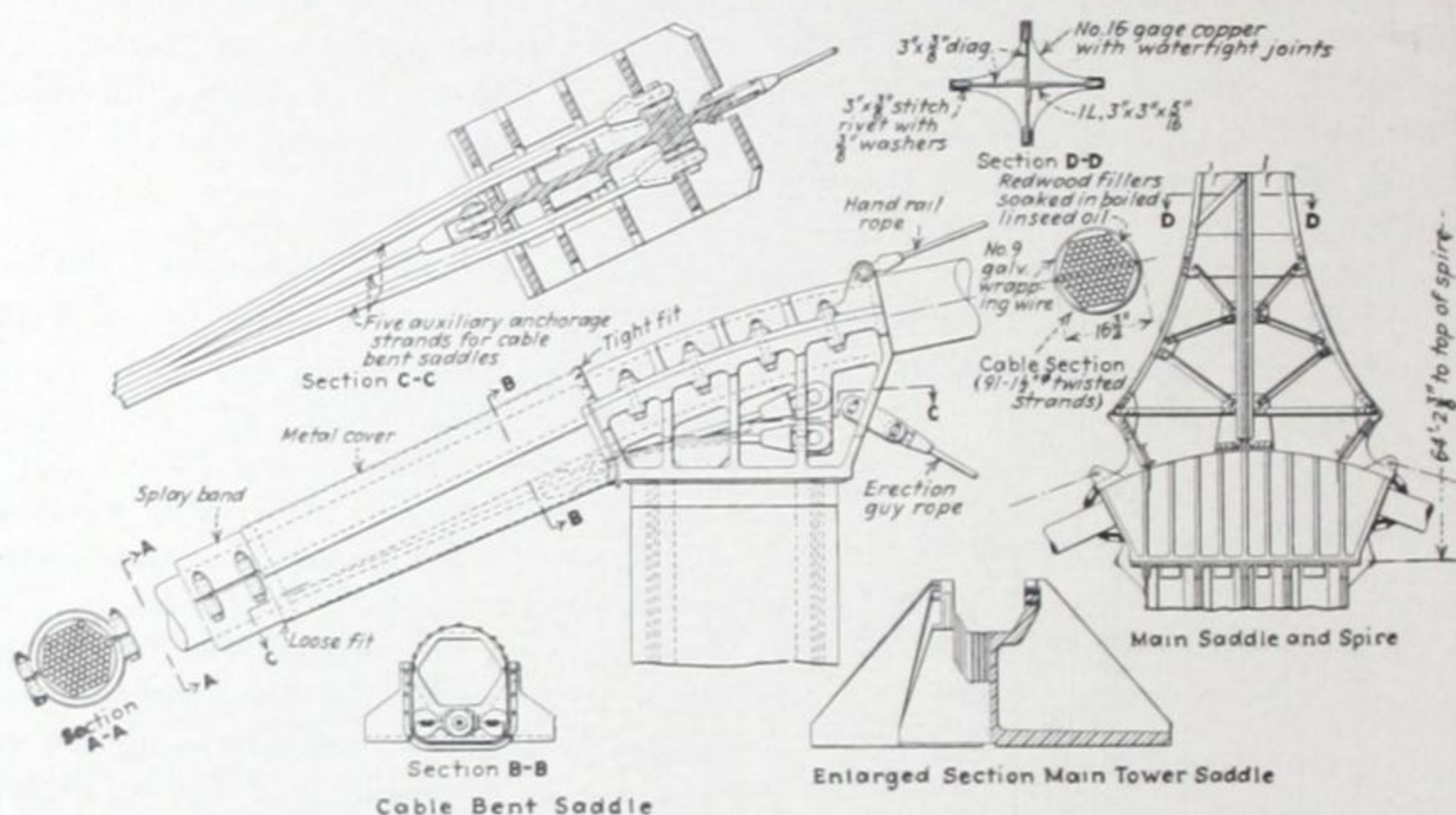


Fig. 6—Saddle Details for Rope-Strand Cable Suspension Bridge

Note use of auxiliary ropes to anchor cable bent saddle rather than depending upon friction clamping of cable in saddle.

The model test results were distinctly reassuring, being in all cases lower than the computed stresses and strains. The indicated maximum transverse deflection of the tower top, referred to the scale of the actual structure, was $2\frac{3}{8}$ in. from 30-lbs. wind load combined with the effect of the resultant eccentricity of the maximum vertical reactions from cable and truss loads. The maximum indicated fiber stress, after adding the computed stress from unbalanced cable pull, was only 14,000 lbs. per sq. in. The model tests showed that the tower was generously proportioned for any

and the center-line sliding bearing for the lateral truss of the suspended side span.

Twisted Strand Cables

Following the successful application in 1928 of twisted strands for the cables of the 949-ft. span Grand' Mere bridge in Quebec (Engineering News-Record, Nov. 18, 1929, p. 841), the specifications for the St. Johns bridge invited bids on twisted-strand construction as an alternative to the parallel wire cable design. The two alternative bids of the John A. Roebling's Sons Company were lower

than any other cables and sh by adopting t Moreover, the expected saving of time of comp saving of time dispensing w footbridges an required for ca

Under the ful bidder on struction also strengthening to carry the in also assumes a tion of details connections. the required s sections of the amounted to l

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The parallel for each cab teen strands c wires each, ye 105.47 sq. in. properties were 225,000 lbs. ul 000,000 lbs. mo cable diameter but the use of tion increased wrapping. An accruing from t was an impro bridge as a w

than any other bids received for the cables and showed a saving of \$42,000 by adopting the twisted-strand design. Moreover, the proposal announced an expected saving of two months in the time of completion of the bridge, this saving of time being made possible by dispensing with the construction of footbridges and by shortening the time required for cable stringing.

Under the specifications the successful bidder on the twisted-strand construction absorbs the cost of the slight strengthening of towers and anchorages to carry the increased cable weight and also assumes any extra cost of modification of details of saddles and anchorage connections. In the St. Johns bridge the required strengthening of the main sections of the towers and anchor chains amounted to less than 2 per cent.

adopted, there are 91 twisted strands of $1\frac{1}{2}$ -in. diameter, yielding a metallic sectional area of 121.64 sq. in. The specification requires the twisted-strand design to match the parallel-wire design in guaranteed total ultimate strength, total yield point and total resistance to elongation. These requirements are more than met by the adopted design, which guarantees an ultimate strength per strand of 135 tons, a yield point of 75 per cent of the ultimate strength and a guaranteed modulus of elasticity of 22,000,000. Actual tests have shown a breaking strength per strand of 150 tons and a modulus of 25,000,000.

The 91 strands lead from a hexagonal cable which after coating with red paste, is to be filled out to a cylindrical section by the addition of segmental fillers of

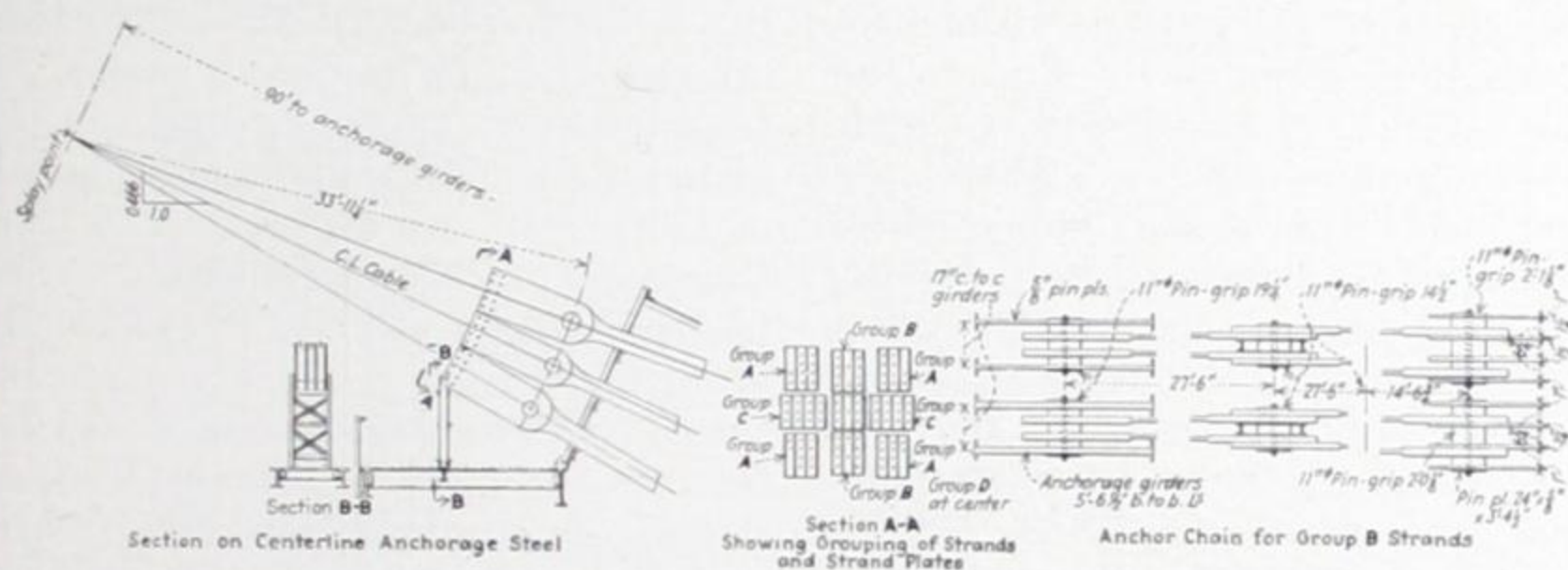


Fig. 7—Anchorage Steel for Rope-Strand Cables

Silicon steel plate chains are used in place of conventional eyebars.

The parallel wire design provided for each cable to consist of nineteen strands of 184 No. 6 galvanized wires each, yielding a sectional area of 105.47 sq. in. The specified physical properties were 170,000 lb. yield point, 225,000 lbs. ultimate strength and 27,000,000 lbs. modulus of elasticity. The cable diameter was specified as $12\frac{3}{4}$ in., but the use of twisted-strand construction increased this to $16\frac{3}{4}$ in. before wrapping. An incidental advantage accruing from the increase in cable size was an improved appearance of the bridge as a whole. In each cable as

redwood soaked in boiled linseed oil. The outside wrapping will consist of No. 9 galvanized wire and three coats of paint.

Main Cable Saddles

One of the problems in twisted-strand cable construction is the limitation of maximum lateral pressure on the strands, as for instance in the cable saddles where the bottom strands are subjected to concentrated vertical pressure from the superimposed strands. It was at first proposed to place a $30 \times 4\frac{1}{4}$ in. curved steel slab horizontally across

each main saddle, dividing the cable and thus relieving the lower strands of the pressure from the strands above. This construction was not ideal, however, since the resulting vertical spread of the cables at the saddles was undesirable because of adjustment and stress considerations.

To aid in a solution of the problem, tests were made at the Trenton plant of John A. Roebling's Sons Company to determine the effect of transverse pressure on the physical properties of the strands under tension. Previously published tests have shown that cable wires are unaffected in strength and yield point, by pressures of 3,300 lb. per linear inch of wire. The test performed for the St. Johns bridge showed that even higher pressures did not affect the physical properties of twisted strands, although they did produce visible deformation of section of the wires in the outer layers. It was decided to limit the maximum pressures to 3,300 lb. per linear inch. This was accomplished by rearranging the strands in the saddle, so as to have eight strands in the bottom layer instead of six and so as to reduce the number of layers from eleven to ten. In addition, the radius of the saddle curve was increased slightly. As a further precaution, the strands of adjacent horizontal layers were designed to have opposite lay, so as to obtain "valley" contact rather than "crossing" contact between the contiguous wires.

The cable bent saddle is a departure from usual design in that anchorage for each saddle is provided by five auxiliary ropes instead of by friction clamping of the cable strands in the saddle.

Strand Assembly

The strand assembly detail (Fig 7) for the anchorage of the strands is similar to that developed for the Grand Mere bridge, except for the increase in scale from 37 to 91 strands. Three tiers

of three groups of parallel vertical plates receive the strands. The groups in the bottom and top tiers anchor ten strands each. The middle group of the middle tier anchors seven strands, and the outside groups anchor twelve strands each. The groups of plates are inclined to face the splay point of the cable, and each group is connected to its anchor chain by an 11-in. pin, except the center group, where a 10-in. pin is used. The plates vary in thickness from 1 to $1\frac{1}{2}$ in. according to the number of strands held. The strand sockets bear against cast-steel blocks, which are held in place between the plates by two long $2\frac{1}{4}$ -in. steel rods going through each group.

Stiffening Trusses and Viaduct Spans

To provide for a 40-ft. roadway and two 5-ft. sidewalks, the stiffening trusses are spaced 52 ft. center to center. A truss depth of one sixty-seventh of the main span, or 18 ft., and a panel length of 19 ft. 3 in. are utilized. The truss chords are of silicon steel with a 45,000 lb. yield point and an 80/95,000 lb. ultimate strength. They are proportioned for a working stress of 32,000 lbs. per sq. in. The maximum working stresses in the medium-carbon steel members are 26,000 lbs. for the stiffening truss diagonals and 18,000 lbs. for the hangars, floor system and bracing.

Only two different sections, two 15-in. channels of 35 and 40 lbs. respectively, are used for the upper chord, the heavier section being required only from the one-sixth to the five-twelfths point of the main span. The lower chord sections also are two 15-in. channels, of 35, 40, 45, and 50 lb. weights respectively.

The truss splices are laid out for fabrication and erection of the trusses in two-panel units, $38\frac{1}{2}$ ft. long. Expansion movement for the main and side spans is provided by supporting the spans on rocker posts at the main towers, as shown in Fig. 2, page 51, and these

rocker posts are brackets extend panels each side connections at the rocker post in bronze bush grease-cup lubric

The layout of was planned for of span and panel special considerations. It pro 180-ft., 144-ft. a truss depths of 18 span lengths and spans. All par These viaduct tr ft. center, the r being cantilever total required wi

Contract Co

The work is d tracts, which v respective lowest

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(2) Fabrication: tion of Bri Wallace E Structural S Seattle

(3) Furnishing an of Cables: Roebling's S pany, Trento

rocker posts are covered by the end brackets extending under two truss panels each side of each tower. The connections at the top and bottom of the rocker posts consist of 6-in. pins in bronze bushings, provided with grease-cup lubrication.

The layout of the approach viaducts was planned for maximum duplication of span and panel lengths, together with special consideration to esthetic requirements. It provides duplication of 180-ft., 144-ft. and 108-ft. spans, with truss depths of 18 ft. for the two former span lengths and 9 ft. for the 108-ft. spans. All panel lengths are 9 ft. These viaduct trusses are deck type, 30 ft. center, the roadway and sidewalks being cantilevered out to obtain the total required width of 50 ft.

Contract Cost and Quantities

The work is divided into seven contracts, which were awarded to the respective lowest bidders as follows:

- | | |
|---|----------------|
| (1) Substructure: Gilpin Construction Company, Portland..... | \$1,026,897.00 |
| (2) Fabrication and Erection of Bridge Steel: Wallace Bridge and Structural Steel Co., Seattle..... | 986,445.80 |
| (3) Furnishing and Erection of Cables: John A. Roebling's Sons Company, Trenton, N. J..... | 472,200.00 |

- | | |
|---|------------|
| (4) West Approach: La Pointe Construction Company Portland..... | 267,603.40 |
| (5) Fabrication and Erection of Viaduct Steel: U. S. Steel Products Company, San Francisco..... | 290,000.00 |
| (6) Concrete Deck: Lindstrom and Feigenson, Portland..... | 146,060.00 |
| (7) Electrical Work: National Electrical Company, Portland..... | 33,000.00 |

The total contract cost was \$3,222,206.20, which was \$572,000 below the estimate of the engineers. The authorized bond issue for the bridge was \$4,250,000, so that allowing for cost of right-of-way, engineering and contingencies, it is estimated that more than half a million dollars of the appropriation will remain unexpended.

Personnel

The St. Johns bridge was designed by Robinson and Steinman, consulting engineers, New York City, and is being constructed under their direction, with R. Boblow as resident engineer. The work is being done under the authority of the board of county commissioners of Multnomah County, consisting of Clay S. Morse, chairman, Grant Phegley and Fred W. German. The highway department of the county is represented by George W. Buck, county roadmaster, and M. E. Reed, county bridge engineer.

Speedy Erection of Parallel-Strand Cable Bridge

On Ohio River structure of 1,060-ft. span at Maysville, Ky. towers were erected in eight days and cables in nine days using footbridges — Aluminum fillers transform hexagonal cable to a 13-in. circle for wrapping

Reprinted from *ENGINEERING NEWS-RECORD*, January 14, 1932

CHARACTERIZED by several important innovations in design and an unusual erection speed, the new suspension bridge over the Ohio River at Maysville, Ky., which was opened to traffic Nov. 25, 1931, assumes a place among the four long-span bridges of parallel-strand type, built since the manufacture of bridge strands of high and uniform modulus of elasticity was perfected about three years ago. The design elements of interest center in the cable make-up and anchorage details. That erection speed was unusual, is evident from examination of the statistics of the job which show that the towers were erected (not riveted) in $3\frac{1}{2}$ and $4\frac{1}{2}$ working days, respectively, and that the cables were erected in nine days. Contrary to previous practice (except for the bridge at Bucksport, Me., under construction simultaneously) and even to general opinion concerning the economics of strand cable erection, foot-bridges were used with satisfaction and success.

The Maysville bridge is one of the large group of public toll structures being built by the Kentucky state highway commission to replace many old ferry crossings. It connects Maysville, Ky., with the village of Aberdeen, Ohio and ties the highway systems of the two states together. This bridge has a main span of 1,060 ft., with suspended side spans 465 ft. long. Plate-girder approaches provide access to the bridge at

either end. Gravity anchorages are used.

The two towers are 165 ft. high above the piers (225 ft. above pool stage) and each contains 350 tons of structural steel. Both towers rest on offshore piers sunk with air caissons. Each cable is made up of 61 pre-stressed twisted strands laid parallel in the cable, giving a finished diameter of 13 in. Cable bents are utilized at each end of the bridge to change the slope of the cable and shorten the distance between anchorages.

Stiffening trusses 14 ft. deep and 28 ft. apart are suspended from $1\frac{3}{4}$ -in. diameter suspender ropes and support a 20-ft. concrete slab roadway and one 4 ft. 8 in. sidewalk at about midpoint between the chords. The bridge provides a 45-ft. clearance at the center of the river at highest high water.

At the present time "innovations" in design of strand cable bridges mean departures from practice used on the three other structures of the type, the Grand'Mere bridge in Quebec, the St. Johns bridge in Portland, Ore., and the Waldo-Hancock bridge at Bucksport Me. In this article only the St. Johns bridge is considered for comparison, because it is the largest and most notable and because the Grand'Mere bridge is not a typical structure is most particulars; the Waldo-Hancock bridge was under construction simultaneously with the

bridge at Maysville
ous innovations



Fig. 1—Strand-cable bridge at Maysville, Ky. Ohio, is an important current tollbridge

On the Maysville of the hexagonal portance. Instead the same diameter Johns, the strands of the hexagonal while the remainder are 1.556 in. in arrangement provided as if all the strands uniformly $1\frac{1}{2}$ in. same time reduced of the finished cable saving in wrapping reducing the size of saddle castings modulus of the cable is the same, since various wires do not vary.

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and Cable

Maysville, Ky.,

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Fig. 1—Strand-cable suspension bridge joining Maysville, Ky., and village of Aberdeen, Ohio, is an important structure in Kentucky's current tollbridge building program.

On the Maysville bridge, the make-up of the hexagonal cable claims first importance. Instead of making all strands the same diameter as was done at St. Johns, the strands forming the corners of the hexagon are 0.942 in. in diameter, while the remainder of the 55 strands are 1.556 in. in diameter. Such an arrangement provides the same steel area as if all the strands had been made uniformly 1 $\frac{1}{2}$ in. in diameter and at the same time reduces the over-all diameter of the finished circular cable, effecting a saving in wrapping costs as well as reducing the size and therefore the cost of saddle castings and cable clamps. The modulus of the large and small strands is the same, since the lengths of the various wires measured along the helix do not vary.

It is also a fact that in a hexagonal cable made up of a number of equal diameter strands, the strands forming the corners of the hexagon protrude to such an extent that segmental fillers of considerable size are required to fill out the cable to a circular cross-section. Eliminate these corners by using smaller strands and much smaller fillers are required to fill out the circle. This pos-

sibility of using small fillers had much to do with the decision to use two sizes of strands in the Maysville cables, for the engineers had prohibited the use of wood fillers, and aluminum fillers costing about three times as much as the wood fillers in the St. Johns cables, had been adopted. These aluminum fillers were in line with the engineers desire to assure maximum permanence in the cables. They were installed in 24-ft. lengths and their arrangement in the cables is shown in Fig. 4, page 61.

At the cable bents an abrupt change in cable inclination occurs, with the result that the cable stress in the backstay is considerably larger than the adjacent stress in the side-span cable. To compensate for this increased stress and to



Fig. 2—Maysville bridge furnishes a 20-ft. highway over the Ohio River.

prevent the cable bent saddle from slipping along the cable, a tier of four 1 $\frac{1}{2}$ -in. diameter strands was added to the bottom of the cable between the cable bents and the anchorages. It was not practicable to utilize aluminum for the large segmental fillers required to finish out the circle in this portion of the cable, and zinc castings, cored out for lightness, were used as shown in Fig. 4.

In the St. Johns bridge these additional backstay strands were fastened to the sides of the cable bent saddles several inches below the bottom strands

of the cable in the saddle grooves. As a result the added strands did not become tangent to the bottom strands of the cable for some distance from the saddle

cable strands throughout their entire length. Wrapping was applied right up to the casting, as may be seen in Fig. 2, page 59. Lead wool calking sealed the

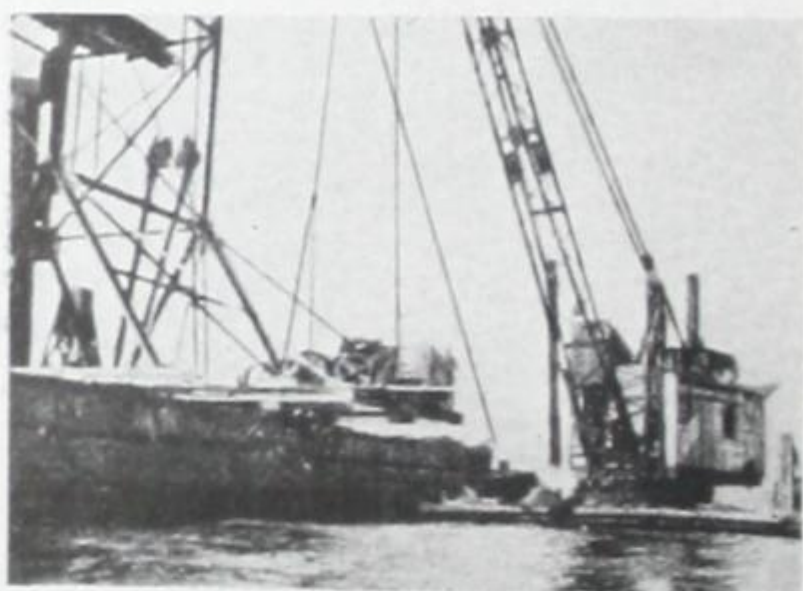
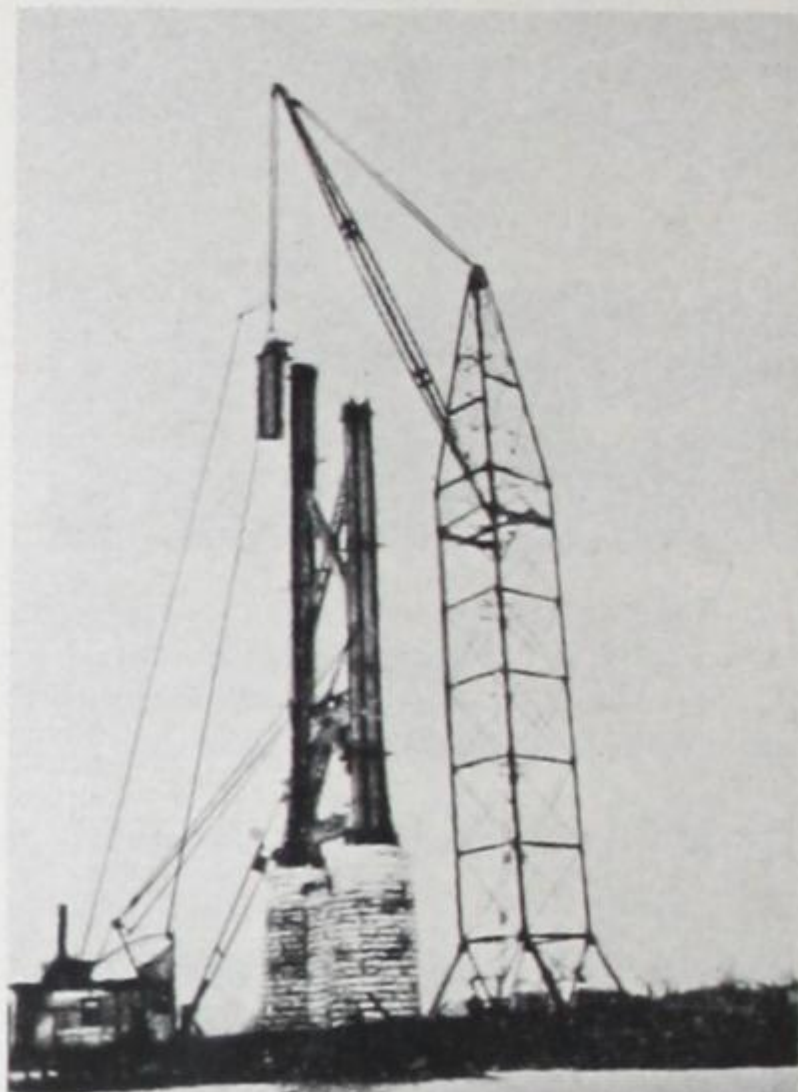
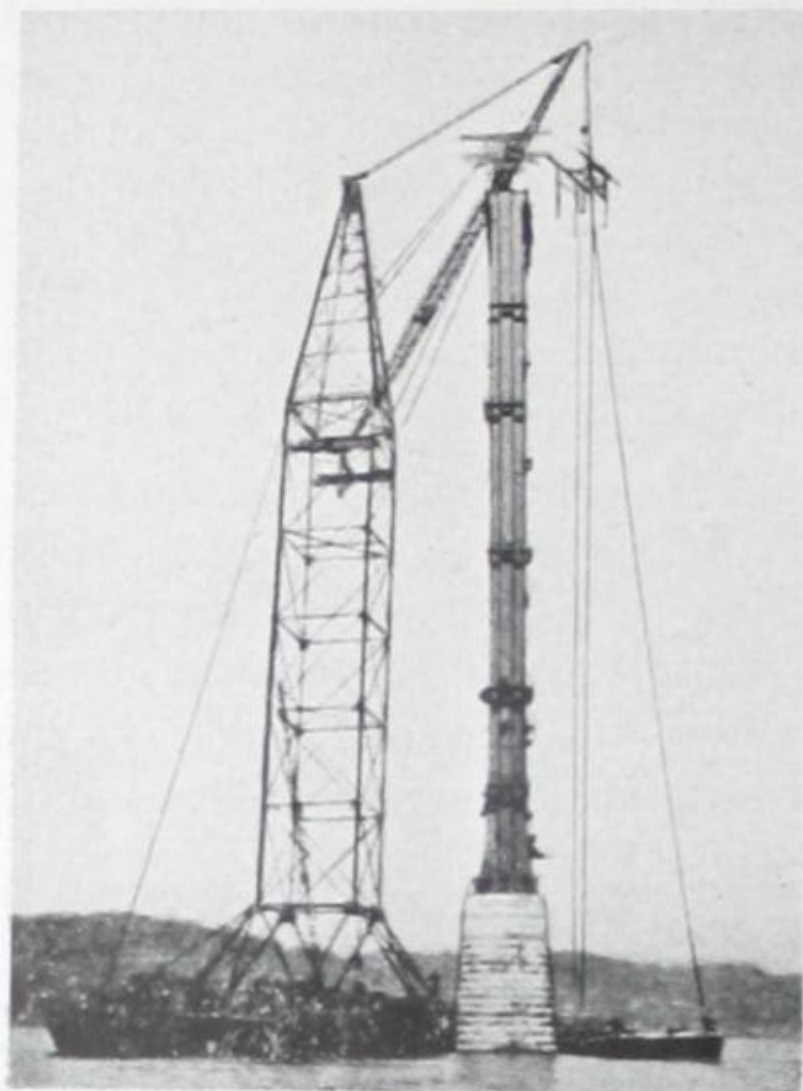


Fig. 3—Floating tower-derrick erected both bridge towers in eight days, including placing cable-erection equipment, as shown at left. The electric hoisting engine placed on an outrigger platform served as counterweight for derrick boom (above). (Right) Steel picked direct from supply barge. Note riveting scaffolds which were attached to leg sections of tower in the barge before erection.

casting, making wrapping in this section impossible and requiring a metal hood for weather protection. At Maysville an ingenious design of saddle casting was worked out (Fig. 4) that keeps the added strands tangent to the main

annular opening at the face of the casting, and no hood was necessary.

A change from the anchorage arrangement used at St. Johns was also effected at Maysville. Beyond the splay point at St. Johns, the strands of each cable were divided into nine parts terminating in nine sets of anchorage plates. At Maysville a single set of plates is placed symmetrically about the center line of the cables. This simplifies the splay arrangement and produces a more compact anchorage, making possible a reduction in the over-all width of the anchorage block. The strands are fastened in the anchorage plates by steel end sockets that bear against cast-steel blocks bolted between the plates. Cast-steel sleeves attached to the strands in the shop, protect the strand where it passes between the bearing blocks. These sleeves are cast with an interior radius to accommodate the inclination of the strand as it leaves the anchorage plates. This assures against

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Erection

These design features, while important, are largely matters of detail. It is in the erection procedure that major departures from recently used methods are most prominent. Towers

placed by a derrick boat with a 130-ft. boom.

Tower Erection

Inasmuch as both towers are located in the river, the contractor elected to erect them with floating equipment. Their height precluded the use of a standard derrick, and a special derrick-tower plant was developed. This erection tower is of steel, 200 ft. high, and

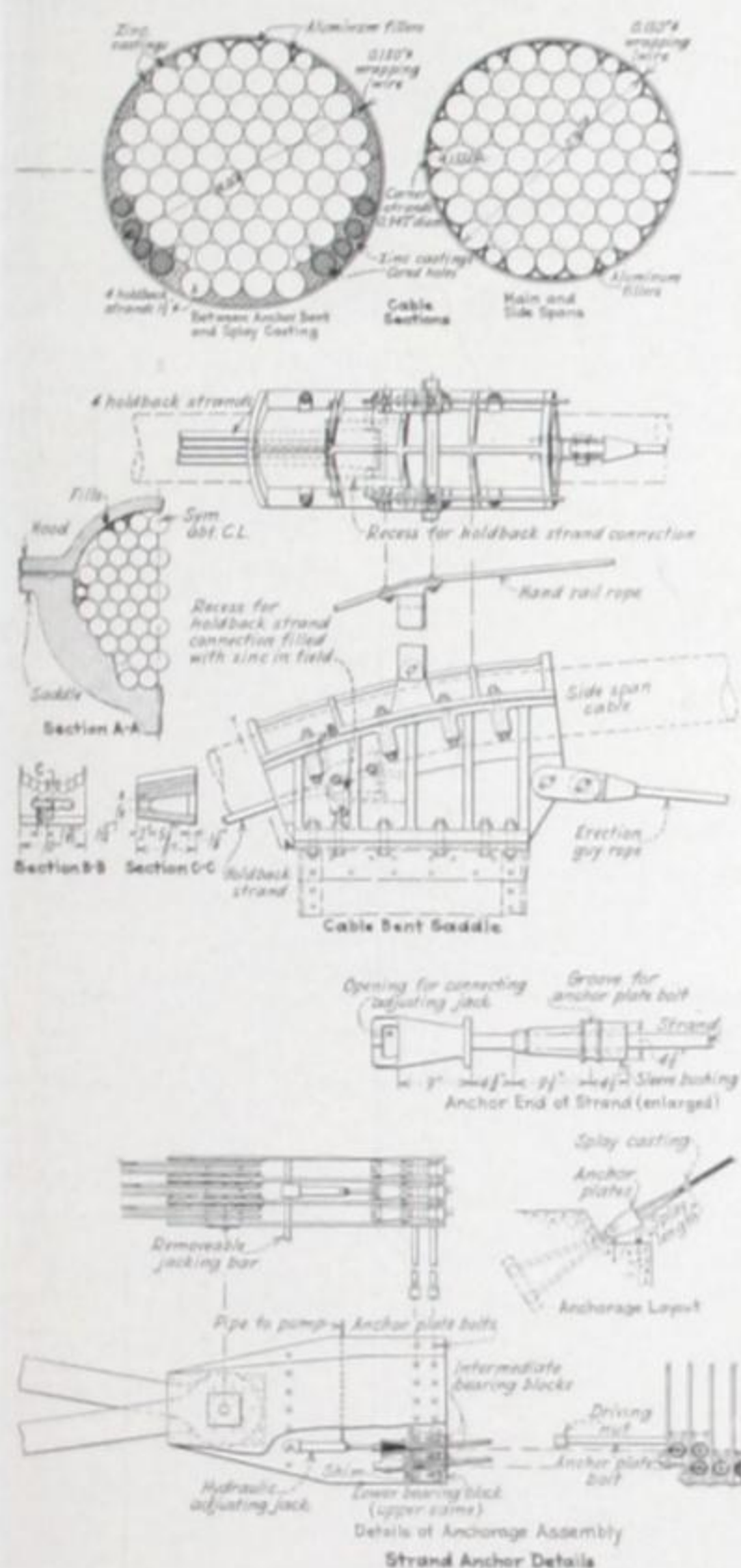


Fig. 4—Cable and anchorage details, Maysville bridge

were erected by a floating derrick tower. Footbridges were used, supported by special ropes and not by the suspender ropes, as is usual practice. Stiffening trusses and floor steel were

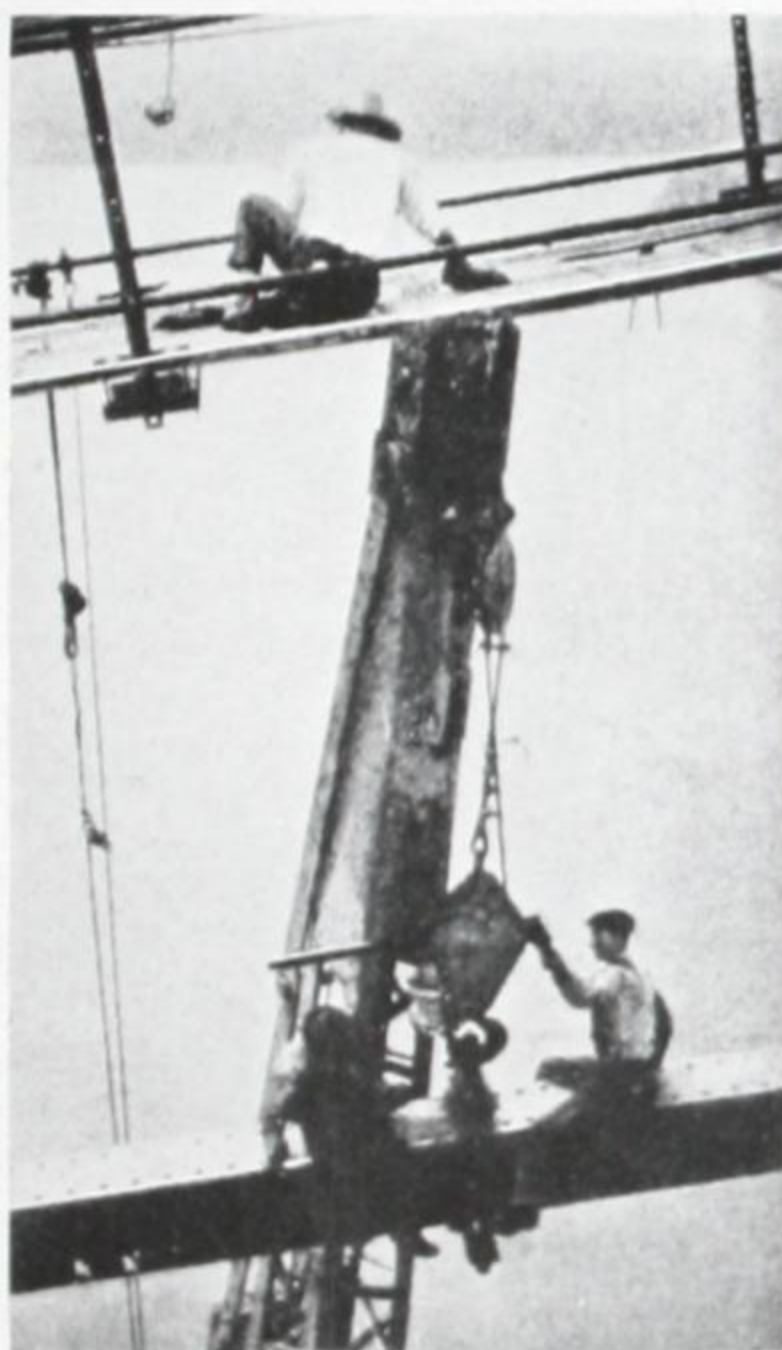


Fig. 5—Use of footbridges for parallel-strand cable erection was important innovation on Maysville bridge. View shows boom of floating derrick setting stiffening truss but also gives good idea of footbridge make-up. Note wood crossbeams held between angle clamps, also perforated channel posts permitting vertical adjustment of footbridge

consists of three principal parts—a wide base made up of trusses resting on timber grillages and spread across two steel barges tied together, a main shaft 21 ft. square, and the derrick mast and boom which are mounted on top of the main shaft. The mast is a pyramid-shaped

extension of the main shaft and was in fact used as a cableway tower in constructing the New Jersey anchorage of the Hudson River bridge in New York.

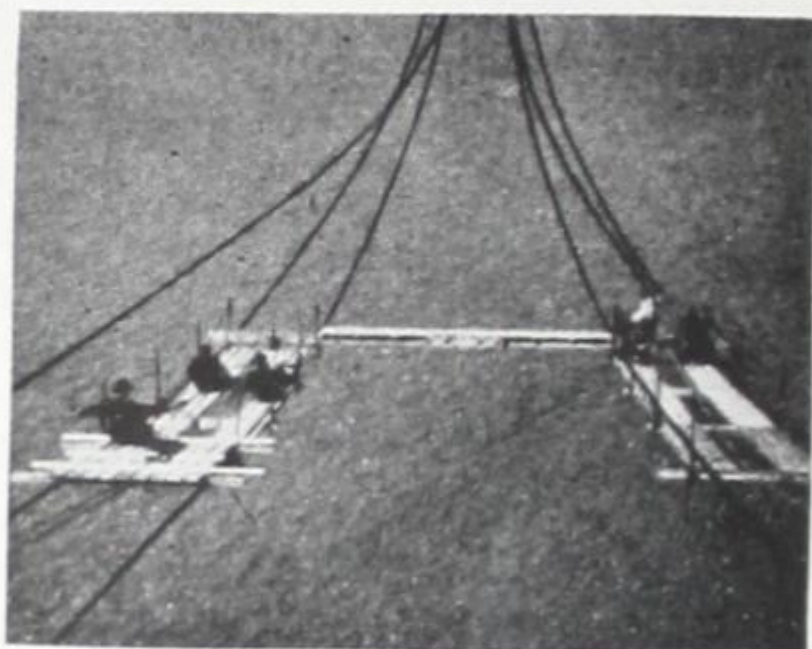


Fig. 6—Erecting footbridges by sliding trains of platform sections down ropes from tower tops

The boom of the derrick is 125 ft. long, a boom seat being provided on the center line of the tower. Guy lines attached to the corners of the barges serve to brace the tower. In addition, the three drum 125-hp. electric hoisting engine that is

used, is set on an outrigger platform at the base of the tower to serve as a counterweight for the derrick boom. In assembling the erection tower, a derrick boat placed the lower panels on the barges, while the remainder of the tower was erected by a gin pole jumped up inside the tower. Two drums of the hoist were used for load and boom lines. The third drum operated a line guy from the top of the erection tower to the anchorage, the tower being maintained in a vertical position by manipulation of the guy line drum.

All erection equipment on the job was electrically operated. Since electric power was not available on the Ohio shore, a special submarine cable was laid from Maysville, Ky., across the river, to furnish current to the Ohio tower and anchorage.

The bridge towers are of the usual braced-leg fixed-base type. Silicon steel is used. Above the roadway the legs are braced by $2\frac{1}{2}$ panels of X-bracing. A horizontal strut is used at the top of

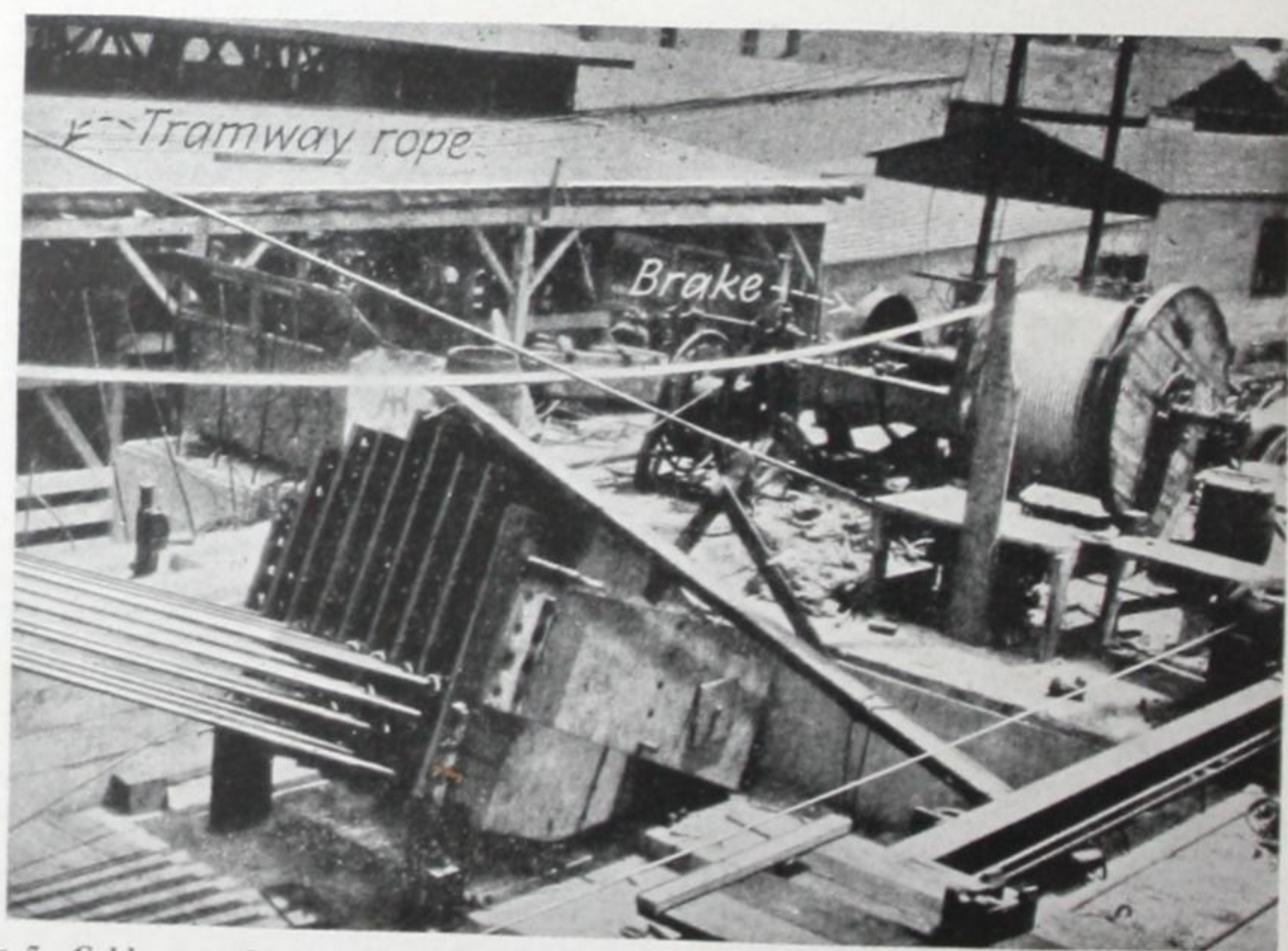


Fig. 7—Cable strands wound on special reels in the field were pulled across the river by an endless tramway rope. Note the compact anchorage requiring a minimum splay of the strands

the tower. Be
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Fig. 8—In construction cable the tramway rope connected through (center) was carried by deflector sheaves supported by rollers while being lifted into the tower (left and right). right and left-lay

the tower. Below the floorbeam is one-half panel of X-bracing and a horizontal strut, $7\frac{1}{2}$ ft. above the top of the pier. Each leg is cellular in cross-section, consisting of a comparatively wide

center cell with narrow cells front and rear. Erection pieces varied in length up to 46 ft. maximum and in weight up to 28 tons.

The Ohio tower was erected first.

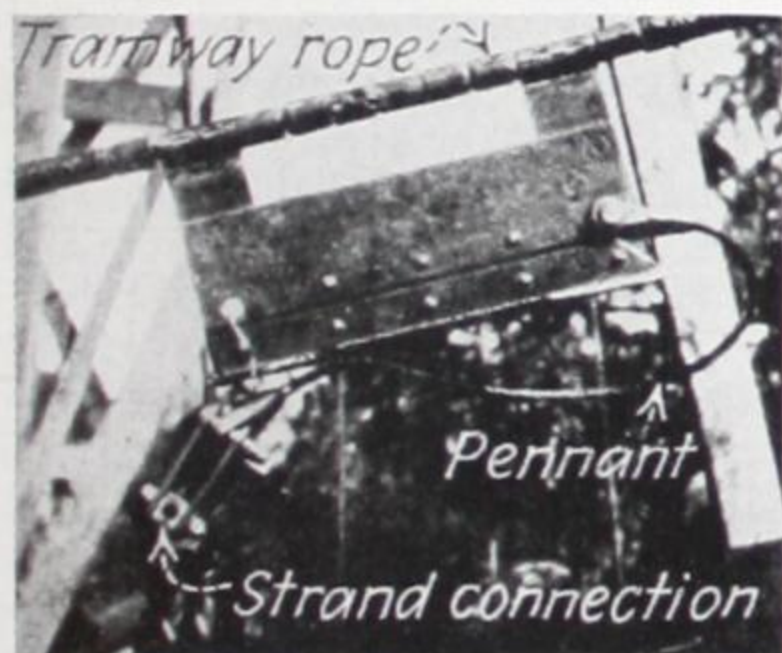
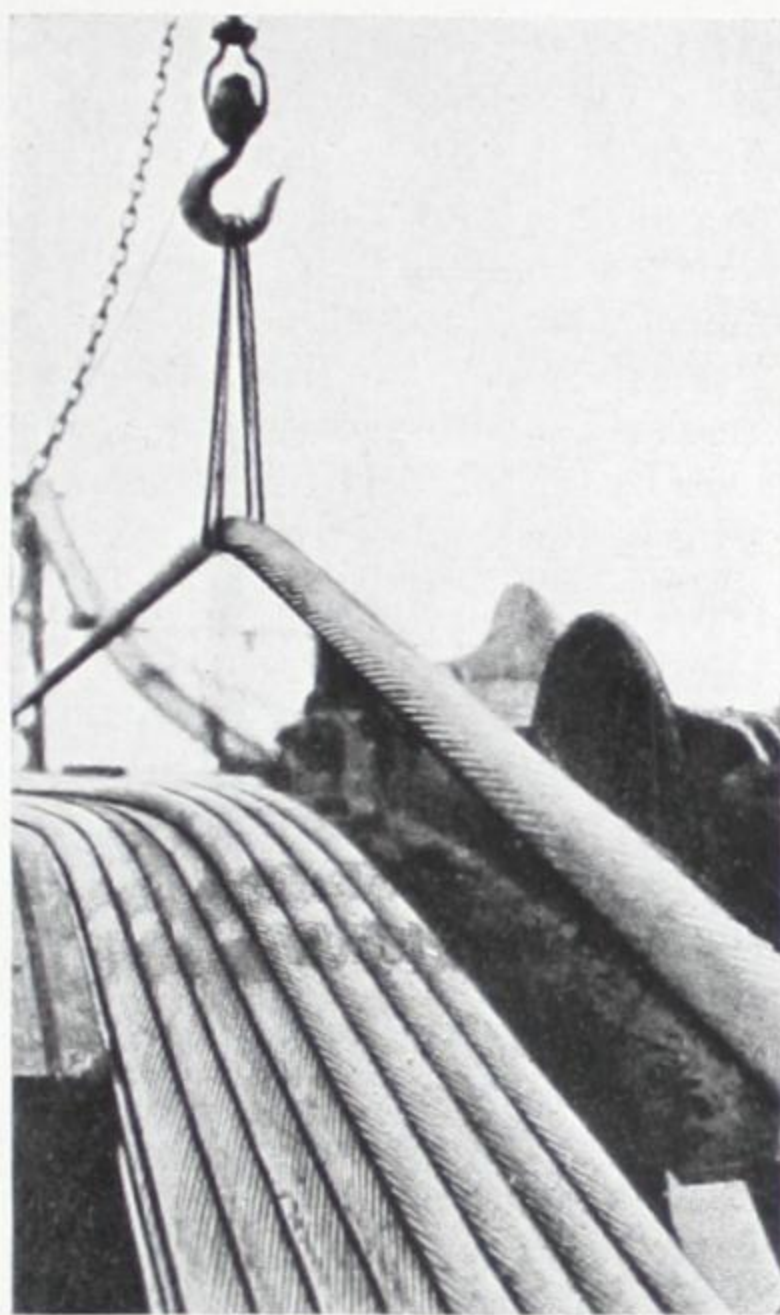


Fig. 8—In constructing the Maysville bridge cable the tramway rope to which strands were connected through a plate and pennant-line (center) was carried at the tower top by a line of deflector sheaves (left). Strands which were supported at the tower tops on four rollers while being hauled across the river were lifted into the saddle by a chain hoist (left and right). In right-hand view note right and left-lay strands in adjacent layers.

Steel came to the job in barges, carefully loaded so that no sorting on the job was necessary. The column bases were set by a derrick boat. Then with the derrick-tower plant lashed to the landward side of the pier, the steel supply barge was anchored to the opposite side. This permitted the erection derrick boom-line to be dropped directly to the steel barge and the steel to be lifted almost vertically into place. Inasmuch as the derrick boom had only about a 10-ft. swing, it was possible to erect only one leg and the bracing from the first position. The derrick tower was then dropped down the river about 20 ft. and the second leg erected. All steel in the Ohio tower was placed in $4\frac{1}{2}$ working days, after which a stern-wheel steamboat moved the erection equip-

ment to the Kentucky tower where the procedure was repeated. With the experience gained in erecting the Ohio tower, it was possible for the erector to place all of the steel in the Maysville tower in $3\frac{1}{2}$ days.

An interesting detail of the tower erection was the attaching of riveting scaffolds to the tower legs before they were hoisted from the barges. This made them immediately available for the raising gang as well as for riveters, and saved time in the field, which was particularly advantageous, since riveting was by far the most time-consuming element of the erection procedure.

The contractor was well satisfied with the use of the floating derrick tower. Work continued in spite of a protracted period of high water, the only difficulty occurring from driftwood that lodged against the barge and pier. Inasmuch as the barges were lashed to the pier, this driftwood was removed with difficulty. On a similar future job, the tower derrick barges would probably be held in position by anchor lines which will permit easier maneuverability.

Footbridges

The engineers' specifications for the Maysville bridge required that footbridges be used when erecting the cables. This is contrary to previous practice on parallel-strand cable bridges, but was believed advisable by the engineers, in order to assure proper inspection, efficient adjustment of the strands and satisfactory wrapping.

Suspender ropes on this bridge were prestressed, cut to length and socketed in the shop and sent to the job ready for erection. This precluded the use of the suspender ropes for footbridge ropes, as has been previous practice. Accordingly, four ungalvanized ropes $1\frac{3}{4}$ in. in diameter and long enough to reach from anchorage to anchorage, formed a part of the footbridge equipment.

The footbridges designed by the con-

tractor were entirely of wood, with the exception of the channel-iron uprights placed at the end of each 10-ft. floor section. Thus they were light and easy to handle. The floor sections were 6 ft. wide, made up of three 8-in. wide planks at either side, with a 2-ft. strip down the center covered with wire mesh which served the twofold purpose of lessening the weight of the footbridges



Fig. 9—Wrapping the Maysville strand cable which was brought to a circular section by the use of aluminum fillers.

and later of permitting openings for the suspender ropes to be made easily. Cross beams (Fig. 5, page 61), placed at the end of each floor section, were two 4x4-in. timbers fastened to the channel-iron posts by small angle clamps, which eliminated the necessity for any bolt holes in the timbers. Bent-plate clevises fastened to the channel posts served as hooks to attach the footbridge to the footbridge ropes. Holes punched in the webs of the channel posts or about 3 in. centers made it possible to place the footbridges at variable distances below the ropes. Such adjustment permitted the footbridges to be lowered as the main cable, under its own

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weight and the weight of the suspended floor steel, sagged down. On previous suspension bridges the foot bridges have been transferred to lashings passing over the main cables when it became necessary to remove the footbridge ropes and cut them up for suspenders. Under such an arrangement the distance between the cables and the footbridges did not vary as the cable sagged down, but with the footbridges entirely independent of the cables, their vertical adjustment became a necessity. The adjustment provision at Maysville proved entirely satisfactory.

As an initial operation in erecting the footbridges, a 1-in. diameter endless tramway rope was carried from the Kentucky to the Ohio shore and back again by a steamboat, and lifted to supports on top of the towers. Machinery for operating the tramway was placed on the Ohio anchorage. This tramway pulled the footbridge ropes across the river and later erected the cables.

With the footbridge ropes in place, the footbridge sections were hoisted to the tops of the towers and slid down the ropes in trains (Fig. 6, page 62). This proved an unusually rapid means of erection, and the footbridges, including ropes and platforms, were placed in six days. The final operation in the erection of the footbridges involved the placing of the storm system. This included a single rope for each footbridge, fastened near the base of each tower and pulled up into an arch outline by means of bridles hung from the footbridges.

Cable Construction

With the completion of the footbridges, headframes were erected along them to support the tramway ropes that hauled the bridge strands of the cable across. Deflection sheaves were also placed on top of each tower and at the cable bents to support the tramway ropes at these locations. A strand connection consisting of a plate with a

pennant line and clevises (Fig. 8, page 63) was attached to the tramway line at both the Maysville and Aberdeen anchorages, one serving each cable. By shuttling these connections back and forth across the river, the strands were laid and the cables built up.

All strands were received by rail on the Kentucky shore and transferred to a special reel stand on the Maysville anchorage block. The tramway carried the Ohio end of only one strand per trip, and strands were placed alternately in each cable.

At the tower tops the strand as it was hauled across, was supported on four large cast-iron wide-mouthed sheaves



Fig. 10—Stiffening trusses and floor steel were lifted into place with 130-ft. boom of crane mounted on float.

set tandem. After attaching the ends of a strand at both anchorages, the strand was transferred from the sheaves to the saddle by means of a chain hoist and a balance beam. The strands were placed in the cable in layers, strands in adjacent layers being of opposite lay to assure line bearing instead of point bearing between the wires of strands in ad-

jacent layers at all turning points of the cable. Also, the use of alternate layers of right- and left-lay strands provides resistance against a rolling effort on the part of the cable caused by the inherent tendency of each strand to rotate as load is applied. In the right and left-lay construction the rotational tendency of one layer of strands is resisted by the same tendency, but in the opposite direction, in the adjacent layer.

The cables were erected in nine days, or a layer per day in both cables. No faster progress was possible because each layer had to be adjusted before another layer was added, and this adjustment could only be done correctly after the sun had gone down.

The suspenders were hoisted to the tower tops and slid down the footbridges to their proper locations. The stiffening trusses and floor steel in the main span and in the portions of the side spans near the towers, were lifted into place from barges by means of a derrick boat with a 130-ft. boom. On the portions of the side spans on shore that could not be reached by floating equipment, a cable-traveler operated by an engine on the shore, set the stiffening trusses and floor steel. No compacting of a bridge

strand cable is necessary but after the aluminum fillers had been applied to fill out the cable to a circular section, a double-spool wrapping machine similar to the one used on the Hudson River bridge, wrapped the cable with No. 9 soft-annealed galvanized wire.

Administration

Contracts for the Maysville bridge were let Oct. 8, 1930. The bridge was opened to traffic on Nov. 25, 1931. The Dravo Contracting Co., of Pittsburgh, started work on the foundations immediately after the contract was let and had piers and anchorages ready so that steel erection started April 1, 1931. The John A. Roebling's Sons Co., Trenton, N. J., erected the entire bridge as well as manufactured and furnished the cables. For this company C. C. Sunderland was chief engineer, C. M. Jones assistant chief engineer, R. J. Cole resident engineer, and Wade Klein superintendent of erection. The Maysville bridge was designed and erection supervised by Modjeski, Masters and Chase, Harrisburg, Pa., for whom C. W. Hanson was resident engineer. For the state of Kentucky, H. D. Palmore is chief engineer and H. R. Creal bridge engineer.



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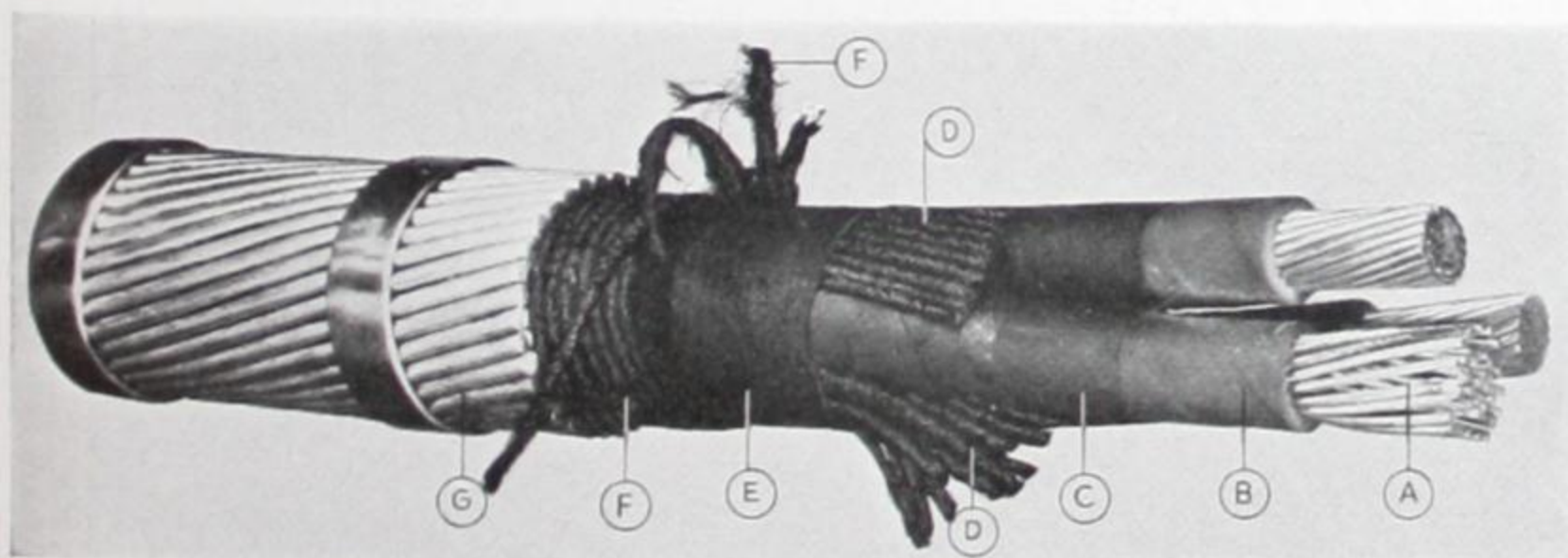


Suggesting the line of the marine power cable used during the erection of the Maysville Bridge

Marine Power Cable in Bridge Building

WHO thinks of a power cable when a mighty highway bridge is opened to traffic? About as much thought is given by the general public to such a cable as is given to a carpenter's nail-set when a sky-scraper is completed. They are both insignificant when the finished product is completed—both, however, play important parts during erection, and design or construction depend to a considerable degree upon their efficiency. With the bridge we think of pillars—foundations—towers cables and decks, and we see the steady stream of traffic speeding across. These are all visible evidences of the engineers' skill and experience.

And yet, back of all of these monuments to the bridge builder's skill are to be found many items of equipment used in erection, that require special engineering and manufacturing ability and experience to produce. The power cable is important in this field. To answer the question—"What's inside of a Power Cable?"—the illustration below shows the construction of the marine power cable used to transmit electric power from one end of the Maysville Bridge (connecting Maysville, Ky., with Aberdeen, O.) to the other end during construction. The bridge and many items of equipment, including the power cable, were products of Roebling.



Marine Power Cable. A—Tinned copper conductor; B—Performance-type rubber insulation; C—Double-faced rubber filled tape; D—Impregnated jute fillers; E—Double-faced rubber filled tape; F—Impregnated jute bedding; G—Double galvanized steel armor wires.



San Rafael Bridge, over the Yaque del Norte River

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The San Rafael Bridge

Over the Yaque del Norte River at Mao, Dominican Republic.
An Intermediate Span Highway Bridge Embodying
New Features of Design

THE San Rafael Bridge, which was opened to traffic on September 24th, 1933, was designed and furnished by and erected under the supervision of the Roebling Company for the Dominican Republic.

The bridge replaces a ferry across the Yaque del Norte River in Santiago Province. It has a main span of 451 feet 7 inches, provides for two traffic lanes (18 feet curb to curb), and is designed for modern highway loading (H-15). In the design of this structure, particular emphasis was placed on economy and esthetic treatment, with what we believe to be most gratifying results.

Economy was obtained chiefly through the use of a light-weight flooring used here for the first time on a suspension bridge, together with parallel, prestressed bridge strands, so grouped as to eliminate the necessity of cable wrapping. Whereas the usual 6 inch concrete slab weighs 75 pounds per foot, the "Belmont Interlocking Channel Floor", together with the Asphalt Plank Covering, weighed only 45 pounds per square foot—a saving in dead weight of 30 pounds per square foot of floor, or a total reduction of 122 tons in the suspended dead load.

This lightening of the floor system effects considerable saving of metal in suspenders, cables, towers and anchorage steel, and reduces the volume of anchorage concrete proportionately to the saving in metallic area of main cables.

Each of the two main cables is made up of nine $1\frac{3}{8}$ inch Roebling Galvanized

Bridge Strands, arranged in a 3 x 3 square. The strands are set three inches apart center to center, and are parallel throughout the main span length. In the unloaded side span there is a slight splay of strands from saddles to the Roebling type Compact Anchorage. This "open" type construction of parallel strand cable permits ready access to all strands for inspection and painting, thereby eliminating the necessity of the costly wrapping operation.

Each strand of the main cable was prestressed, and measured to exact length while under working tension, at the same time centerline of saddles and cable band positions were marked off and identified, thereby reducing field adjustment and location work to a minimum.

The "open strand" design of cable not only made for economy, but added materially to the pleasing appearance of the bridge. Had the wrapped cable been used, the diameter of the finished cable would have been $4\frac{1}{8}$ inches. As it is, the apparent diameter is $7\frac{3}{8}$ inches with the resulting accentuated sweep of the graceful curve.

The tower tops and saddles were given unique treatment in that the saddles are built unto the main columns below the top line of the upper portal, thus eliminating the usual protuberance atop the main towers.

Transportation and material handling facilities dictated that the weight of a single piece, as shipped, should not exceed 4,500 pounds, and its length be kept under 21 feet. Both requirements were fulfilled.

Native labor solely was used during erection; the only man on the job with previous experience on suspension bridges being a member of the Roebling Bridge Engineering Staff. That the superstructure was completed and the bridge opened to traffic within ten weeks, is convincing evidence of the ease with which the suspension bridge may be erected—provided, of course,

that the work is carefully planned and then executed under competent supervision.

The San Rafael Bridge, embodying the latest developments of design, with its clean-cut, direct and graceful lines, marks another step forward in bridge history. The economy and beauty of the intermediate span suspension bridge for public highways is established.



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The George Washington Bridge

*Over the Hudson River—connecting 179th Street, New York City,
with Fort Lee, New Jersey.*

The Bridges of '31

FEW years, if any, show the erection of a larger number of bridges than 1931—bridges of many types to meet the constantly increasing demand of transportation and industry; and no

the work of John A. Roebling, the Master Bridge Builder, it seems more than a coincidence that such an epochal year should mark the centennial of the landing of John A. Roebling in America.



Fig. 1—Maumee River Bridge. A suspension bridge of '31 opened to traffic in October. An inter-city bridge connecting two business sections, over the Maumee River at Toledo, Ohio. The five traffic lanes and two footwalks of the bridge combine with rail, water and air to meet the transportation requirements of this important industrial community

single year in American history, in fact in the history of any country, records the completion of four *major* suspension bridges. It is to this latter group, as illustrated, that we call your particular attention.

When we stop to consider that these four bridges are suspended on wire, and that wire for such purpose had its genesis, as we know it in America, in

This year not only shows the continuation of the *Roebling Idea* in the use of wire as a suspension bridge medium, but of even greater significance is the fact that the wire for these four bridges is cold-drawn from acid open-hearth steel—an evidence of its particular adaptability when metals are held in tension.

While the cable construction in all of these bridges is similar, in that the

Fig. 2—Maysville, Ohio. It is the Parallel Strand Factor in the water, rail, and air.

strands are laid in the formation of the strand. In two, George Washington River, the strands are laid in parallel. In the latest development—the Prestressed concrete—adopted.

The same general principle—used on the B. & O. other super-suspension since that time, of the cables of this group—parallel formation placing these cables, which wrapping, became

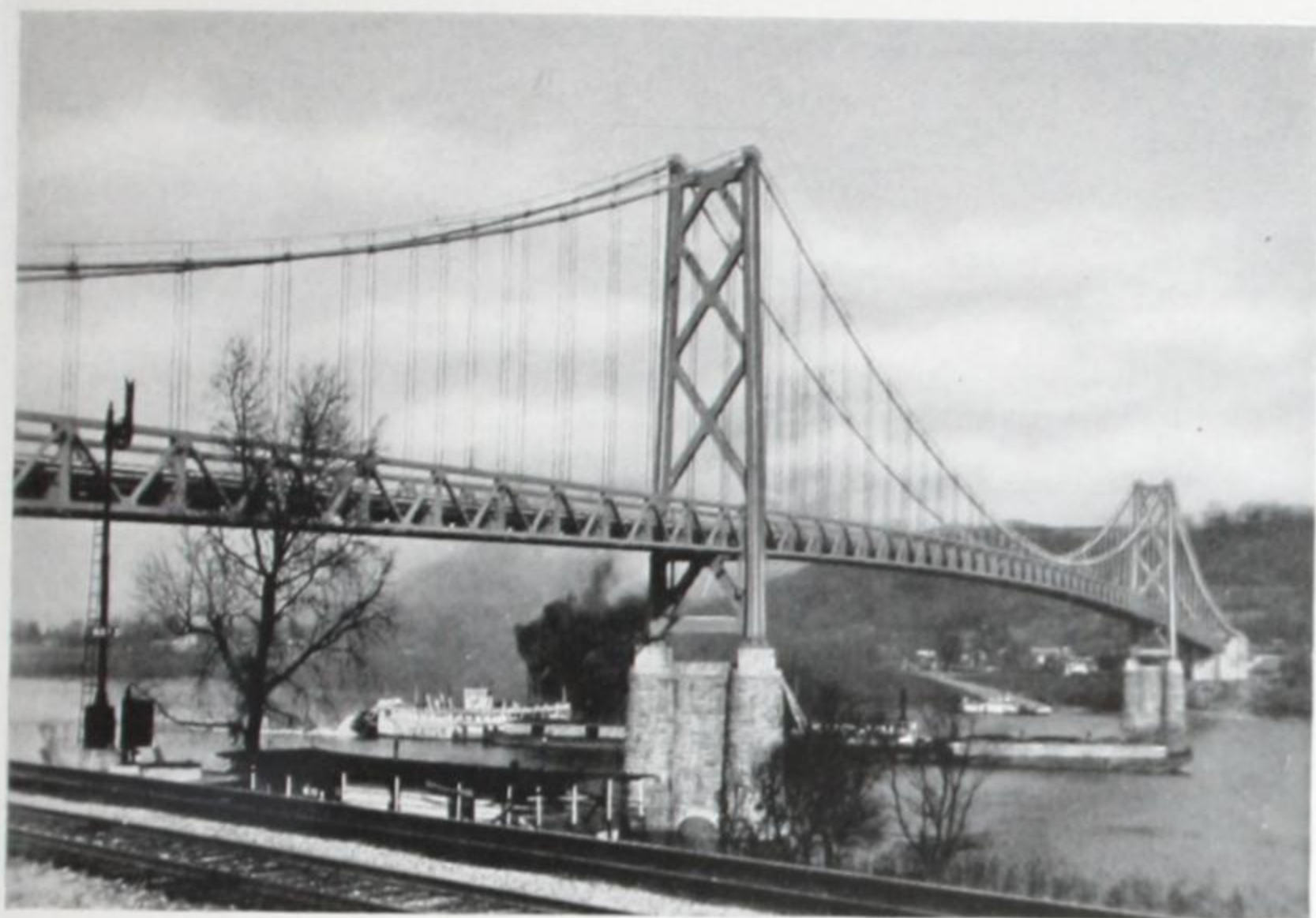


Fig. 2—Maysville—An inter-state bridge—between Maysville, Ky., and Aberdeen, Ohio. It is the second largest highway bridge to be suspended from Prestressed Parallel Strand Cables. Its two traffic lanes and one sidewalk constitute an important factor in the transportation facilities of this section, where here, as pictured, water, rail, motor and if the camera had snapped a second later, air—each plays its part in meeting the needs of modern travel and industry.

strands are laid parallel, the construction of the strands differs. In the first two, George Washington and Maumee River, the strands are made up of single wires laid in parallel formation and the strands are then laid parallel in the cables. In the latter two, Portland and Maysville, however, the strands are of a different construction, and here, the latest development of the *Roebling Idea*—the Prestressed Bridge Strand—was adopted.

The same general method of cable erection—the “aerial stringing process”—used on the Brooklyn Bridge, and all other super-span suspension bridges since that time, was used in the stranding of the cables for the first two bridges of this group—laying wire-by-wire in parallel formation into strands and then placing these strands, parallel, into cables, which after compacting and wrapping, became the completed cable.

The entire cable erection on the first two bridges—from strand to completed cable—was a field operation. The strands for the Portland and Maysville bridges, however, were plant-made, prestressed and cut to predetermined lengths, then shipped to the bridge sites. The strands, instead of single wires, were strung in the field and laid in parallel formation into the cables.

The successful development of the process of prestressing in bridge strands, necessary in this new development, is considered one of the most important advances in the suspension bridge field for many years. A comparison of the general differences in strand and finished cables is pictured in illustrations, Figs. 5 and 6, page 75, and in the detailed comparison as given in Table I, page 76.

While it is impossible to predict what the developments in suspension bridge engineering will be for

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Fig. 4—St. Johns. This bridge takes its place in the Bridges of '31 as the longest Prestressed Parallel Strand Cable Bridge in the world. An urban-to-interurban bridge connecting business and residential sections crossing the Willamette River, at Portland, Oregon. Four motor lanes and two sidewalks is its contribution to the traffic needs of this city.

any other year, it is hardly likely that it will have the same marks of distinction—four major suspension bridges open for traffic in the single year. And yet, with the momentum of interest and engineering development of the past year and continued research in the use of wire as a suspending medium, it is difficult—if not impossible, to predict what bridge engineering of the future will produce.

Notes on Table I

Page 76

NOTE 1—The strands for the cables of the first two are composed of (434 and 186) single wires laid in parallel formation as indicated by Fig. 5, Sec. a, page 75, and are designated as Parallel Wire Strands. One cable of the George Washington Bridge comprises 61 strands of 434 wires each or a total of 26,474 wires in each cable.

NOTE 2—The wires in the strands of the last two are not parallel, as in Fig. 5, but are laid in a helical form as indicated by Fig. 6, Sec. a, and are known as Prestressed Bridge Strands. These strands like the strand in Fig. 5, are laid parallel in the bridge cable as illustrated in Fig. 6, Sec. b, and form the new type of bridge cable referred to in the accompanying article as one of the most important advances made in recent years.

NOTE 3—The wires in the strands and in the completed Parallel Wire Cables are all of the same diameter, (.195 in. for the first two bridges in Table I) but in the strands of the Prestressed Parallel Strand Cable, wires of different diameter are used to make as compact a strand as possible. In Fig. 6, Sec. a, it will be observed that wires of five different diameters are used.

NOTE 4—It will be observed in Fig. 5 that after the strands have been compressed a circular cross-section is secured, whereas in Fig. 6, Sec. b, the strands form a hexagon and to complete the circular cross-section, fillers of wood or metal are used. Segmental sections of Port Orford cedar were used in the Portland Bridge and aluminum and zinc for the Maysville Bridge.

Fig. 5—Parallel Wire Strands. Represents a strand of 434 wires (a) and (b and c) compressed.



Fig. 6—Prestressed Parallel Strand Cable. Represents a strand of 1295 wires (a) and (b and c) compressed.

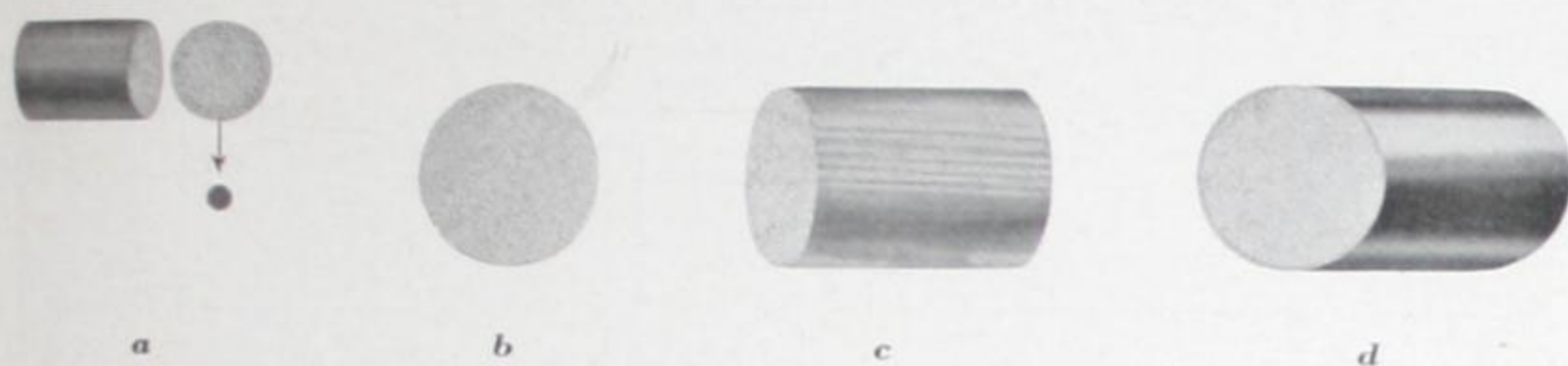


Fig. 5—Parallel Wire Cable—the type of cable on the George Washington and Maumee River Bridges. The strands of the George Washington Bridge made up of 434 wires (a) measure $4\frac{1}{2}$ in. diameter, or 1-16 the diameter of the compressed cable (b and c) comprising 61 strands or a total of 26,474 parallel wires in each cable. The completed cable, wrapped, as indicated by section d.

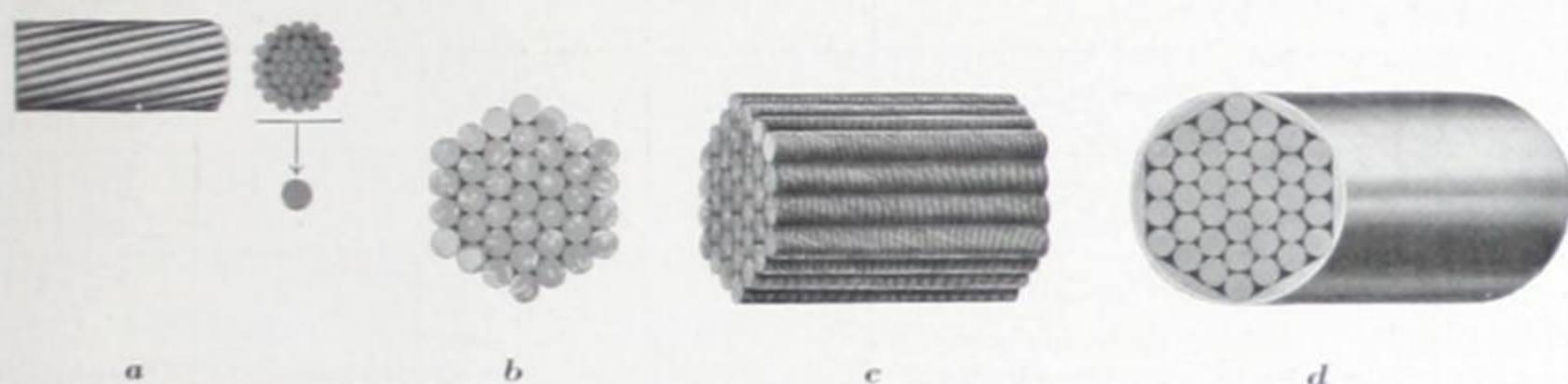


Fig. 6—Prestressed Parallel Strand Cable—the latest development of the Roebling Idea in bridge cables, used on the St. Johns, the Maysville and other bridges, Sec. a, represents a strand, $1\frac{1}{2}$ in. diameter, containing a number of wires of different diameters. Sec. b and c—the hexagonal assembly containing thirty-seven Prestressed Parallel Bridge Strands (a) preparatory to wrapping, Sec. d shows segmental pieces of wood or metal to complete the circular cross section. The cable, illustrated, contains 1295 wires and measures $8\frac{3}{4}$ in. before wrapping—the cables of the two bridges, referred to in this article, are of this construction, with 91 strands of 51 wires, and 61 strands of 61 wires, respectively.

SUSPENSION BRIDGES OF '31 COMPARED

TABLE I

a.	Name.....	George Washington	Maumee River	St. Johns	Maysville
b.	Location.....	Hudson River Ft. Washington, 179th St., N. Y. City	Maumee River Toledo, Ohio	Willamette River Portland, Oregon,	Ohio River Maysville, Kentucky,
c.	Date of Erection.....	1927-31	1929-31	1929-31	1930-31
d.	Length of Main Span in Feet.....	3,500	785	1,207	1,060
e.	Number of Cables.....	4	2	2	2
f.	Number Strands Per Cable.....	61	19	91	61
g.	Diameter of Strand in Inches.....	4½	3	1½	1½
h.	Diameter of Cable (before wrapping) Inches.....	36	13¼	16½	13½
i.	Number of Wires in One Strand...	434	186	51	61
j.	Number of Wires in Main Cables..	105,896	7,068	9,282	7,442
k.	Total Strength of Main Cables in Tons.....	350,000	24,660	25,000	16,470
l.	Total Weight of Wire in Main Cables in Tons.....	28,500	675	1,150	656
m.	Total Length of Cables Between Anchorages in Feet.....	5,212	1,780	2,719	2,288
n.	Diameter of Individual Bridge Wire in Inches.....	.195	.195	(See Note 3)	(See Note 3)
o.	Height of Towers in Feet.....	635	220	344½	229½
p.	Number of Single Part Suspenders at Each Panel Point of Bridge..	16	8	8	4
q.	Size of Suspenders in Inches	2⅞	1⅝	1⅝	1¾
r.	Fillers.....	None (Note 4)	None (Note 4)	(Note 4)	(Note 4)
s.	Engineers.....	Port of N. Y. Authority O.H. Ammann Chief Eng'r	Waddell & Hardesty	Robinson & Steinman	Modjeski, Masters & Chase

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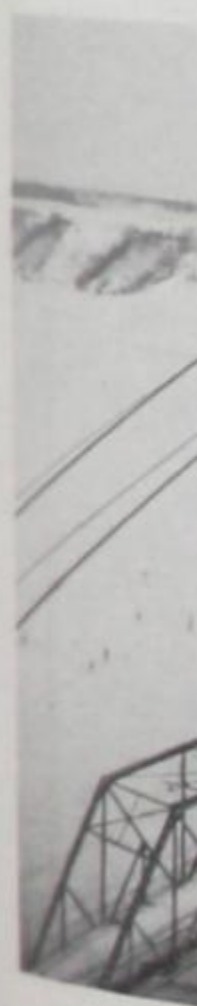




Fig. 1—The Grand' Mere Bridge—Completed

Contrasts in Bridge Building

BUILDING two bridges - - - one where the freezing of the river governed the choice of erection methods, and the other where a dry river-bed of the summer season was a governing factor—these are the interesting contrasts to which we direct your attention.

The first of these bridges is over the St. Maurice River at Grand' Mere, Quebec, on which the steel and cable erection was commenced and completed in the winter season, when the tempera-

ture went as low as 25° F. below zero and the ice was from 24 to 30 inches thick.

The second, at Dome, Arizona, where the spinning of the cables had to be done during the night hours to permit of uniform strand tension, on account of the extreme temperature changes that reached 110° F. above zero in the day-time and dropped to normal and more uniform temperature at night.

The Grand' Mere Bridge is the first long span suspension bridge in Canada,



Fig. 2—The Grand' Mere in course of construction

ARED

Johns	Maysville
lamette River rtland, regon,	Ohio River Maysville, Kentucky,
929-31	1930-31
1,207	1,060
2	2
91	61
1½	1½
16½	13½
51	61
9,282	7,442
5,000	16,470
1,150	656
2,719	2,288
Note 3)	(See Note 3)
344½	229½
8	4
1⅝	1¼
Note 4)	(Note 4)
inson & inman	Modjeski, Masters & Chase



Fig. 3—Dome, Arizona, Bridge

and the largest multiple-strand cable bridge in the world at the time of erection—the St. Johns Bridge, at Portland, Oregon, then in course of erection, exceeding the length by approximately fifty feet. The use of galvanized bridge-strand is unique in the structure of such long spans—the main span of the Canadian bridge measuring 949 feet. This bridge is a stiffened suspension structure with straight backstays. Each of the two main cables contain thirty-seven $1\frac{1}{4}$ -inch diameter galvanized steel strands with 35 wires to each strand, making a total of 1295 wires in each cable. The strands were measured under specific tension for cutting length, and marked at calculated points corresponding to tower-centers and span-center. Two strands for each cable were also marked at the cable-band centers to serve as guides in placing the bands. Special sockets were placed on the strands before shipment. The application of the method of using galvanized steel bridge-strands cut to



Fig. 4—Anchorage, Dome Bridge

specific length when measured under tension, was developed by the Roebling bridge engineers and work done at the Roebling plant.

The Dome Bridge, on the other hand, while of the same general super-structure, has the parallel-wire type of main cable, each cable being made of three strands of 290 wires each, or a total of 870 wires in each completed cable, these wires measuring 0.162 inches in diameter. The main span in this case being 802 feet long. The cables for this bridge were spun in a horizontal

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position on the ground and hoisted to the tower tops after completion.

These two bridges with the contrasting topography are pictured in Figs. 1 to 4 on preceding pages and similar degrees of contrast follow through practically every method of construction, but the same basic *Roebing Idea* of using steel wire to suspend bridges is seen in both projects.

Note the portal in the tower piers of Fig. 3, whereas in the Grand' Mere Bridge the structural steel carries the portals. Of passing interest—Fig. 1 shows a suspension bridge along the nearest bank supporting a pulp-wood conveyor. This bridge is also constructed of Roebing cables.

We parallel the picture stories of the building of these two bridges so that

Fig. 5—Grand' Mere Bridge

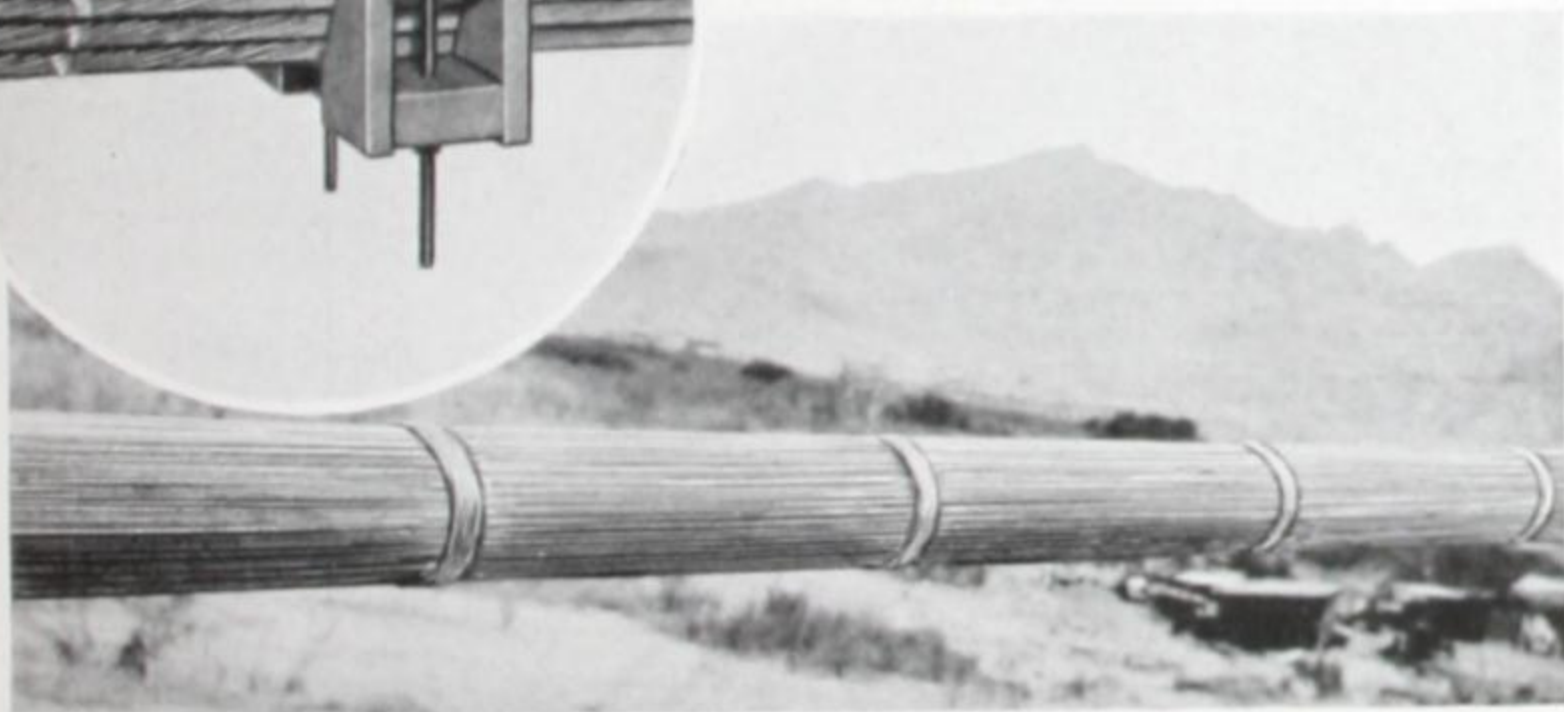
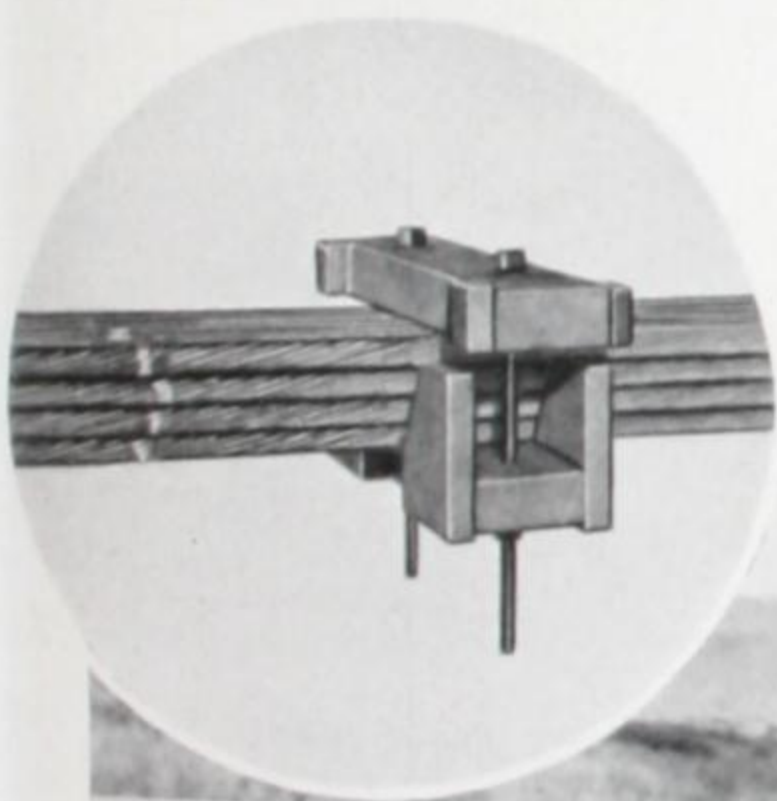


Fig. 6—Dome Bridge Cable

Bridge are shown in Fig. 5. In order to fill out the hexagonal of the assembly of 37 strands into a circular section, (cable diameter being $6\frac{5}{8}$ inches) segmental redwood strips, $\frac{1}{2}$ -inch thick were placed immediately in advance of the wrapping of the wire. The redwood strips were soaked in boiling linseed oil before placing. No. 9 galvanized steel wrapping wire was used to complete the cable.

Fig. 6 shows one of the two Dome Bridge cables which contains 870 wires, (.162 inch in diameter). The completed cable measuring $5\frac{1}{2}$ inches in diameter is wrapped with No. 10 galvanized iron wrapping wire.

The strands on the Grand' Mere Bridge were made at the Roebing plant, whereas for the Dome Bridge the spinning was done at the bridge-site as pictured in Fig. 8, page 81. Here the frame and sheaves are shown attached to a truck to carry the loops of wire during the 145 spinning-trips per strand. Fig. 10 gives the layout of the spinning fields

our readers may the more clearly see the contrasting methods of cable erection and the more easily follow through this story of contrasts.

The relative position of the strands in the main cable of the Grand' Mere

showing the bridge towers in the distance. The procedure of shaping the strands for serving is indicated and a served strand is shown at the right.

Fig. 9 shows the strand supported by horses on the ice, in readiness for

the lift to the towers where the cables are shown partly completed.

Still following the work at Dome Bridge, Fig. 17, page 84, pictures the anchorage for the strands during the spinning operation. The serving at the splay not far from the strand shoe indicates how all the 145 loops of wire were grouped together to total 290 wires in each strand. In the spinning layout (Fig. 18) supports are indicated for the wires being spun into the strands for the Dome Bridge. The electric lights shown here were installed to permit the spinning at night which was

bed of the Dome operation, preparatory to hoisting into position. This strand has 290, No. 8 wires. Figs. 12 and 13, page 82, show views of the two anchorage methods. The first being the thirty-seven $1\frac{1}{4}$ -inch diameter strands of the main Grand' Mere cables as they splay out to connect by means of sockets, on the anchor plates. The second shows the Dome connections of cable strands to anchor eyebars. In Fig. 15, page 83, three developments of the Dome strands are shown: (1st) a strand being spun, (2d) a completed strand, (3d) one complete strand partly seized. In contrast to



Fig. 7—Dome

made necessary due to the great temperature changes during the day. In the background, rollers are shown upon which the completed strands rest while being hauled out across the river in preparation for the lift to the towers.

In Fig. 19 we have the contrasted layout of the Grand' Mere cable forming operation. Horses and adjusting tower are shown at the center of the main span in Fig. 16, page 83, on the ice.

In Fig. 7, we see the start for the haul of the strands across the dry river-

this is a practically completed Grand' Mere cable. Horses along the line of the cable and adjusting tower at the center of the main span are again shown in Fig. 16,

In the hoisting of the strand cables to the tops of the towers, we find the same method used on both bridges. Fig. 21, page 85, the completed strand of the Dome Bridge is shown being hoisted to the cable saddles on the tower tops. In Fig. 20 the same method is shown in hoisting the strand to the tower top of the Grand' Mere Bridge.



Fig. 8—Top-

In this story indicated erection of wire bridges—Roebing Idea—fo On the Dome use of the ground because of the sm and the compara cables, not just

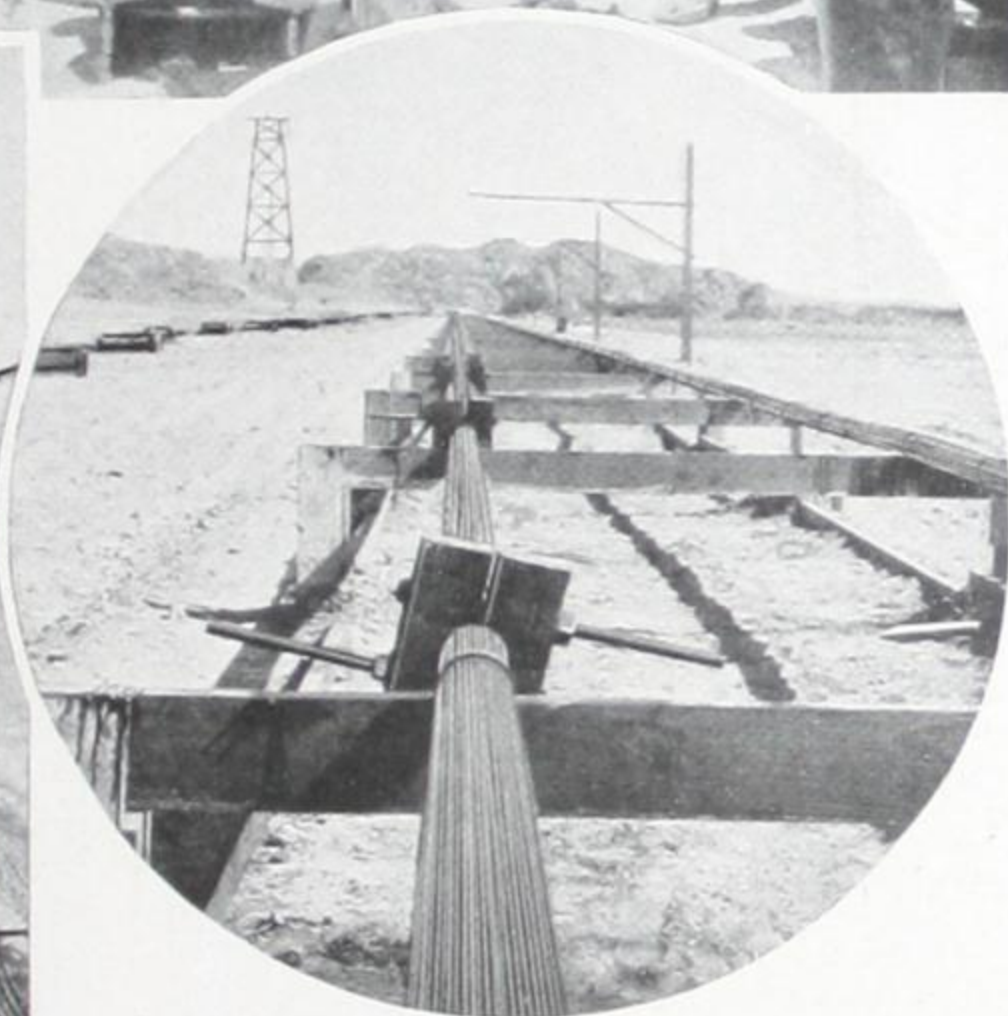
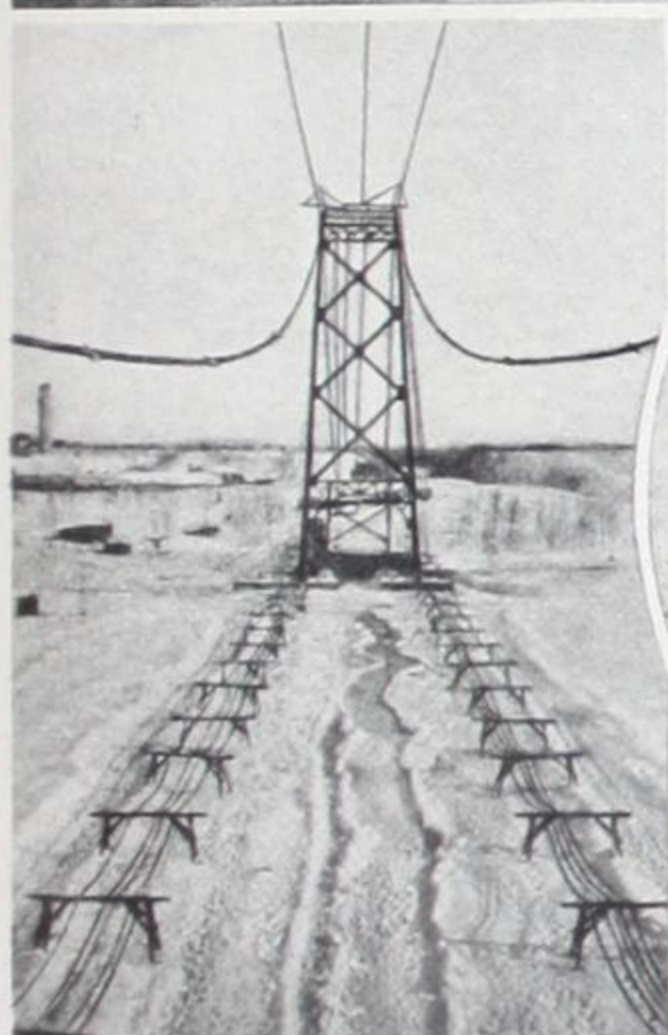
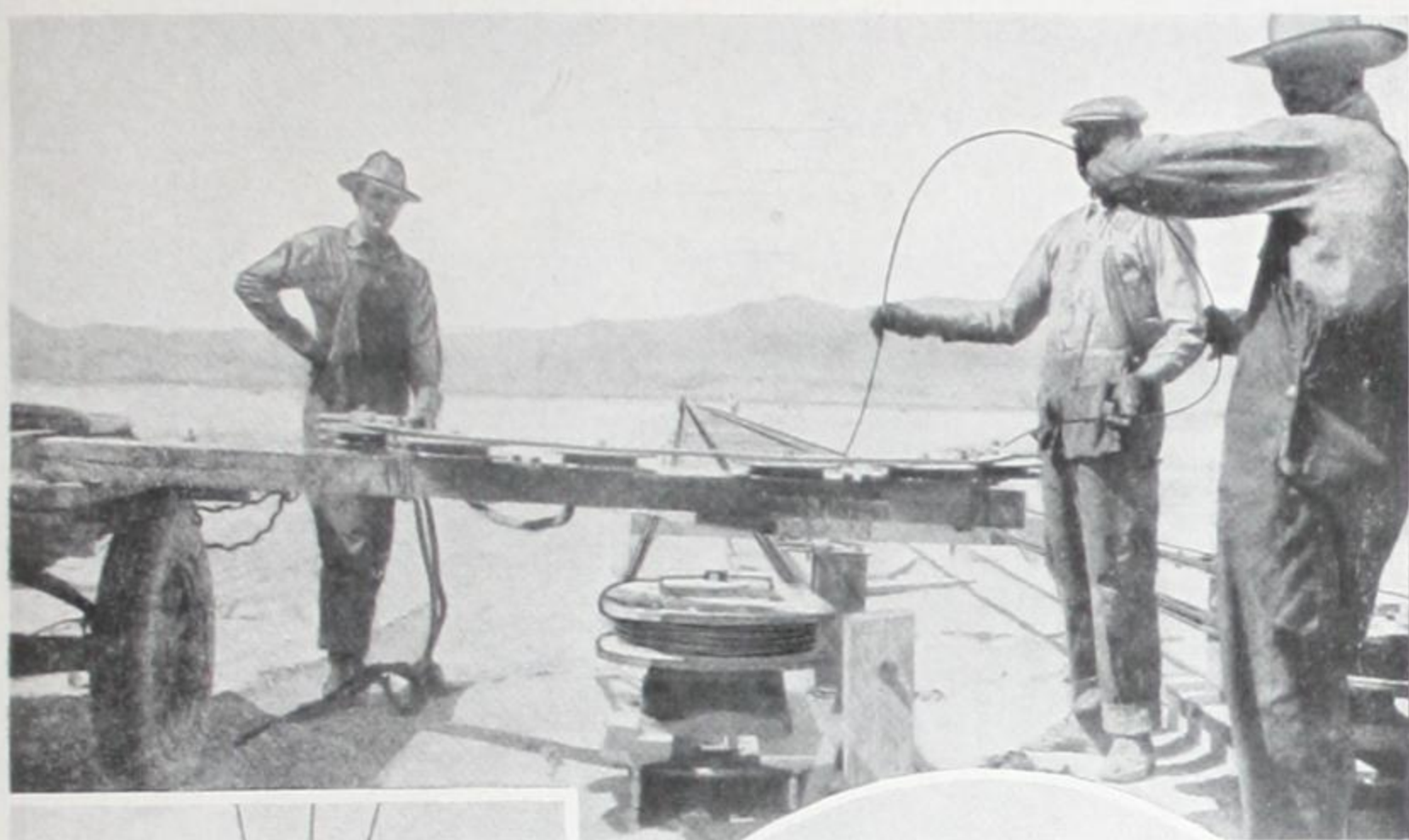


Fig. 8—Top—Dome

Fig. 9—Left—Grand' Mere

Fig. 10—Circle—Dome

In this story of contrasts we have indicated erection methods of two types of wire bridges—developments of the *Roebing Idea*—for short-span bridges. On the Dome Bridge project the use of the ground method of spinning because of the small number of strands and the comparatively small diameter cables, not justifying the expense of

footbridges, which constitute such an important part in the construction of parallel-wire bridge cables by the aerial spinning method, especially on the longer super-span bridges like the Hudson River Bridge. For the sake of economy and because of natural conditions and advantages, footbridges were not used in either of these instances.

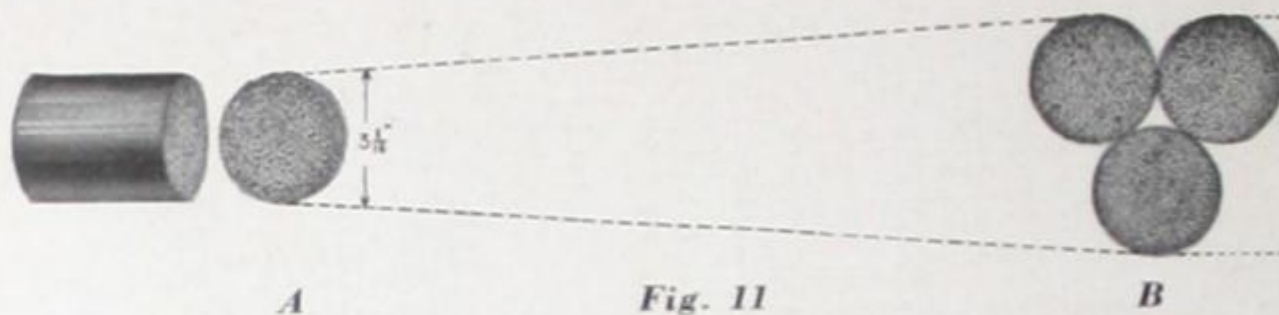


Fig. 11

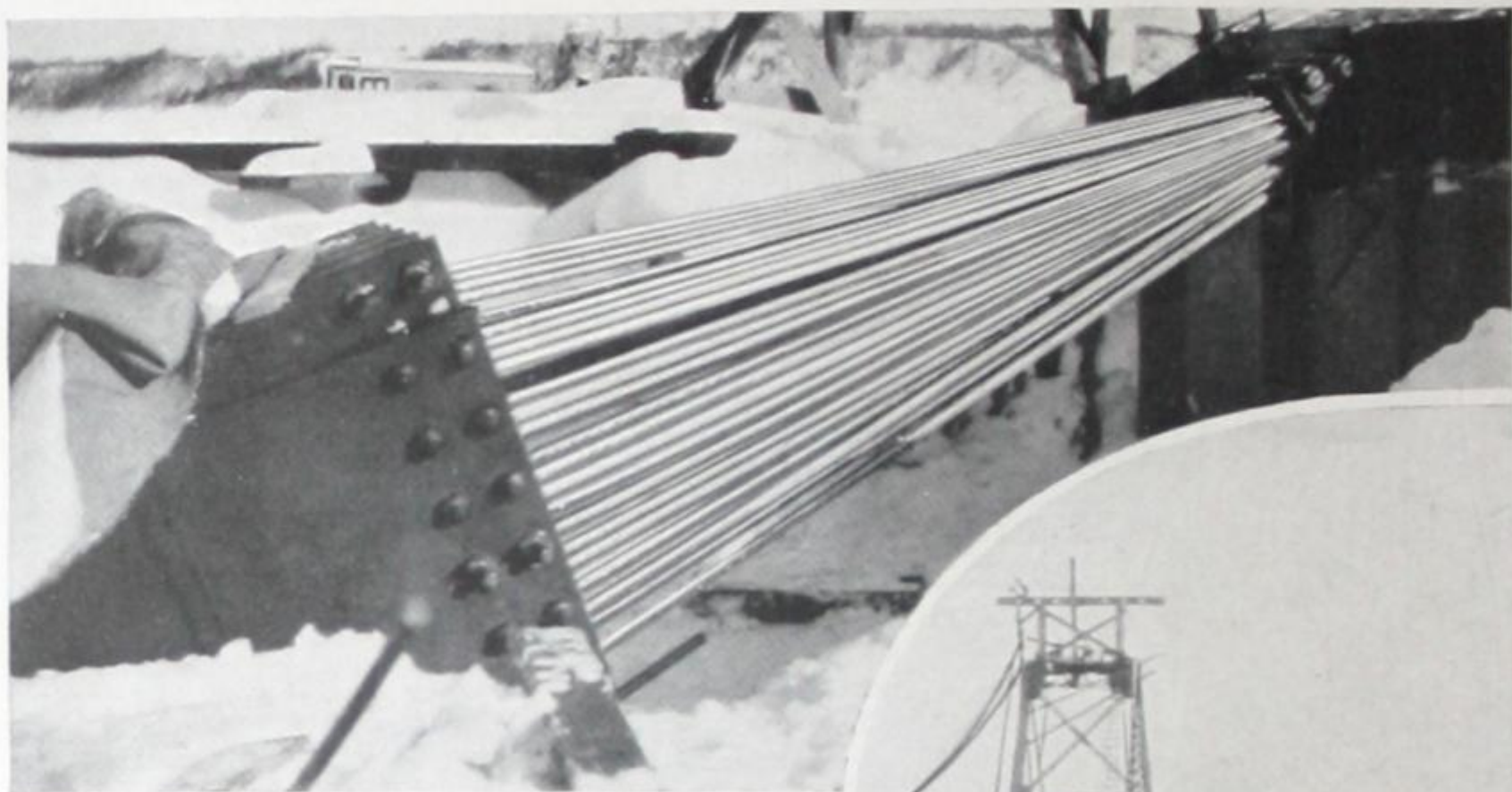


Fig. 12—Grand' Mere Anchorage

PARALLEL-WIRE MAIN CABLE

Fig. 11

A.—Parallel-Wire Bridge Strand, $3\frac{1}{16}$ in. diameter, containing 290 galvanized wires of .162 in. diameter, laid parallel as shown in Fig. 10, page 81, and Fig. 13, right.

B.—Strand assembly before being compressed into circular shape.

C.—Cross-section showing the three strands of 290 wires each, compressed previous to wrapping, containing total of 870 wires for each cable.

D.—Showing the single wires in parallel form in contrast to the bridge-strands in parallel form as indicated in Fig. 14 C.

E. and F.—The completed Parallel-Wire Main Cable after wrapping.

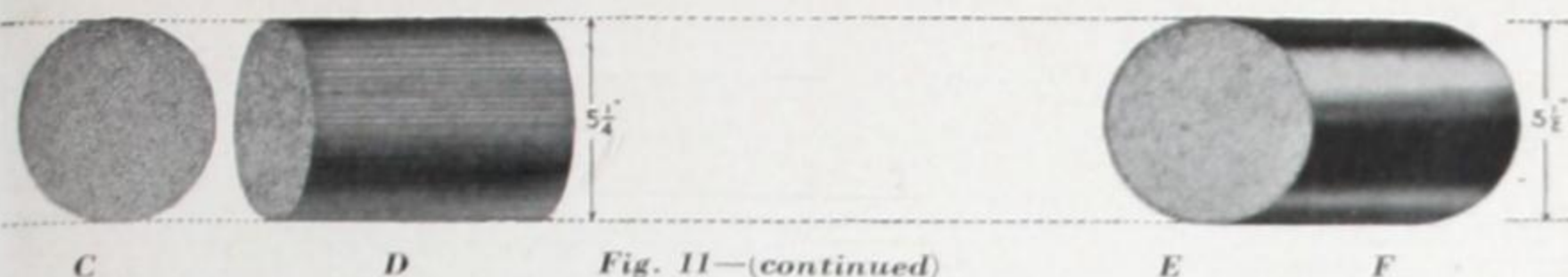


Fig. 13—Dome Bridge Anchorage.



Fig. 14

Multiple-Strand Main Cable—
Grand' Mere Bridge



MULTIPLE-STRAND MAIN CABLE

Fig. 14

A.—Galvanized Bridge Strand, $1\frac{1}{4}$ in. diameter, containing 35 galvanized

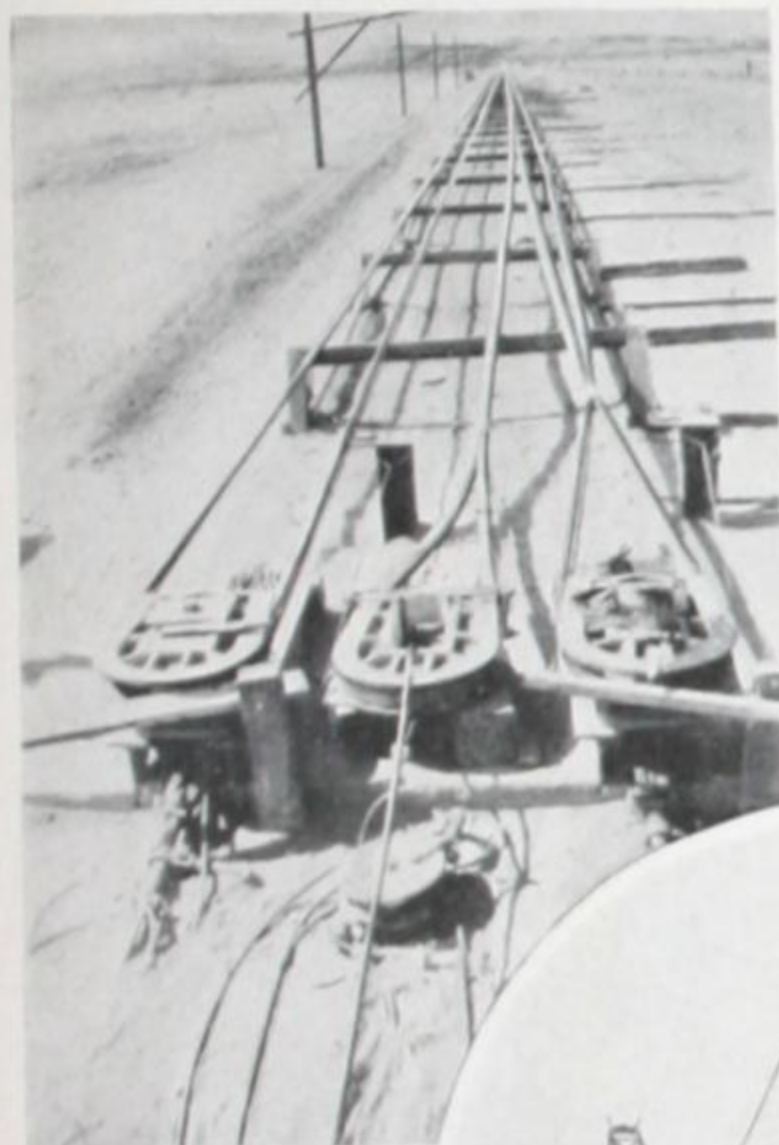


Fig. 15

wires of several diameters—center wire measures .192 in., next lay contains 6 wires—.186 in. around which are laid thirteen wires alternating diameter—.148 in. and .197 in. The seventeen wires forming the outside have a diameter of .195 in.

B.—Hexagonal assembly containing 37 bridge strands (A) clamped and ready for wrapping.

C.—Each bridge strand laying in parallel formation. 37 strands (A) of 35 wires each are combined in cable (C) to make a total of 1295 wires in each cable.

D.—The hexagonal assembly with segmental pieces of redwood to complete the circular forms.

E.—The completed Multiple-Strand Cable after wrapping.



Fig. 16

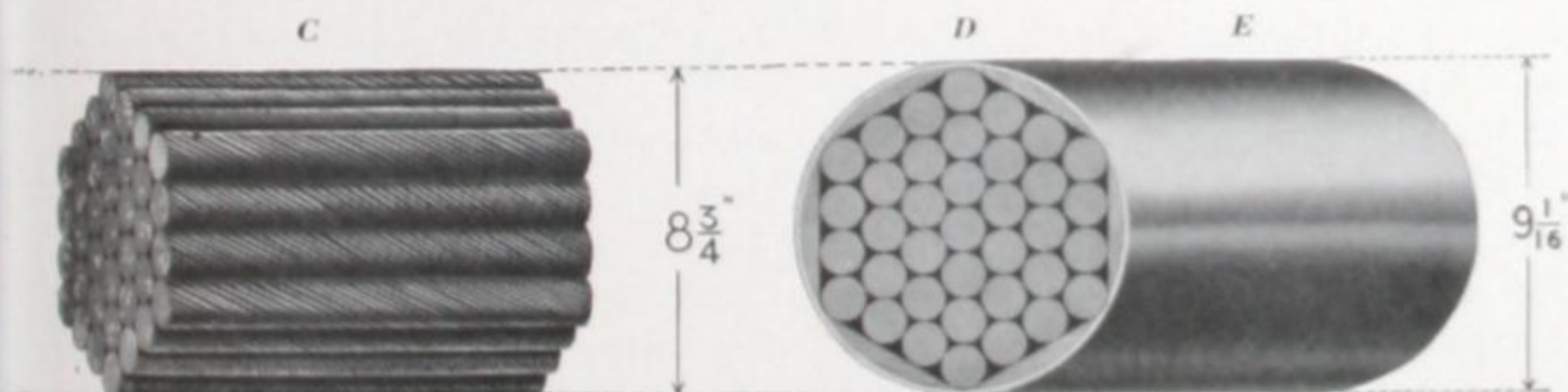


Fig. 14—(continued)

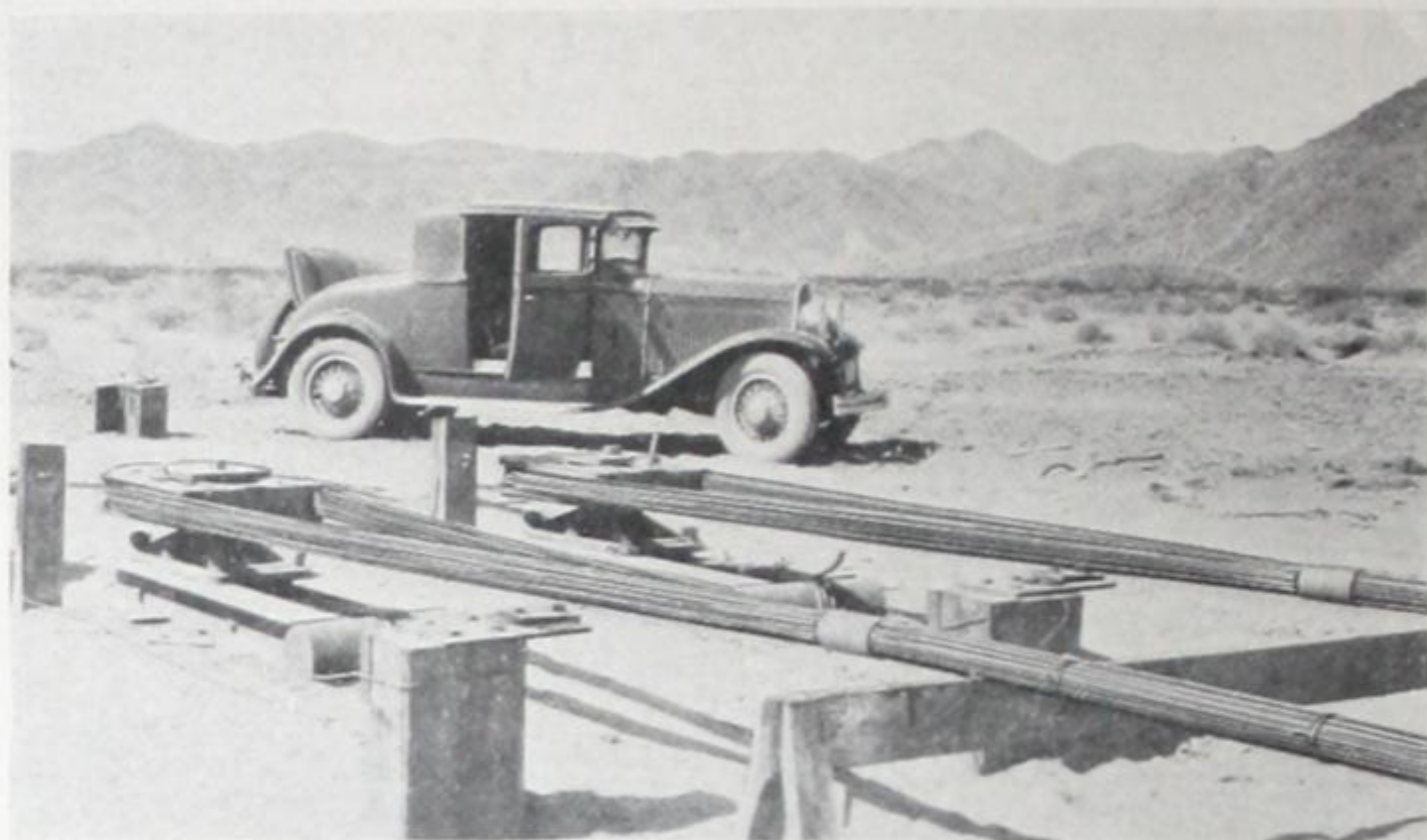


Fig. 17—Dome

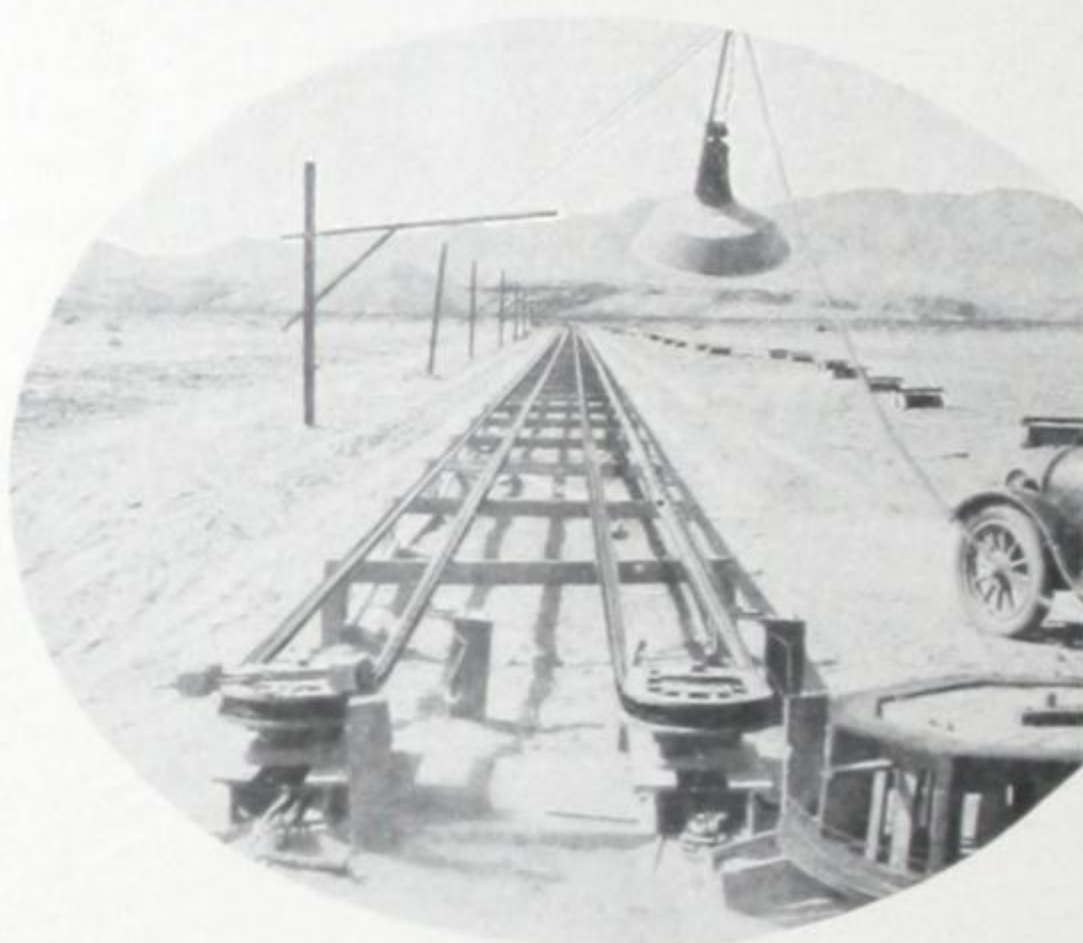


Fig. 18—Dome

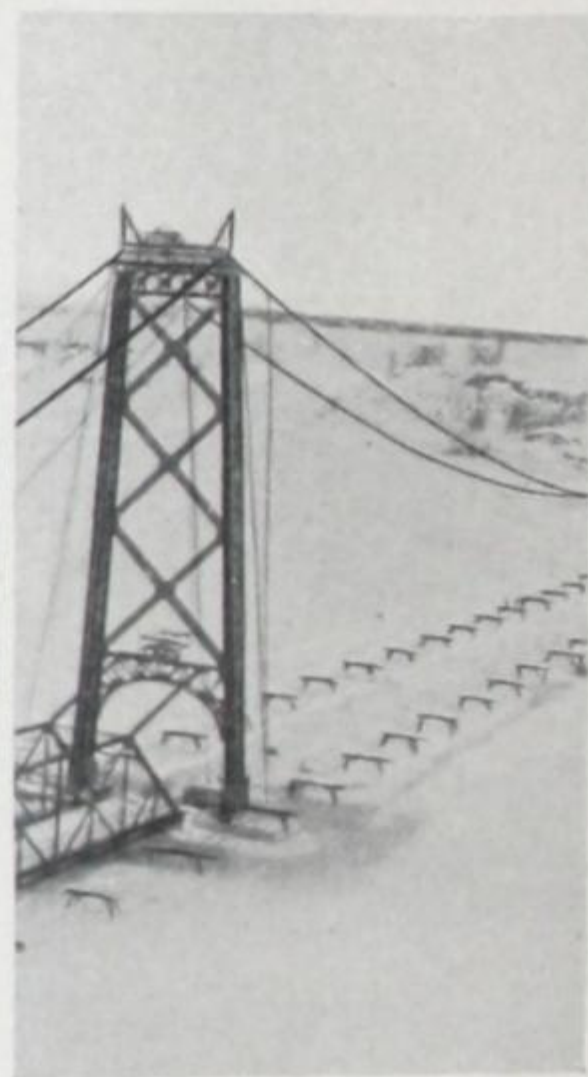


Fig. 19—Grand' Mere

Figs. 11 and 14, pages 82 and 83, giving the progressive steps of these two types of main bridge cables, are included here for a clear understanding of the different constructions.

While the parallel-wire cable is, today, the most generally used method for long and super-span suspension bridges, there is a point in cross-sectional cable area where the multiple-

strand main cable is most practical and economical. The St. Johns Bridge at Portland, Oregon, is an instance of the use of multiple-strand construction on bridges with longer spans than the two in the story of contrasts—the main-span being 1207 feet. There is, however, no set rule because the many governing factors in the selection of the best method of con-

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a close study of
any project.
Multiple-strand
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struction, can only be determined by a close study of all of the factors of any project.

Multiple-strand cables for main spans, a development of the *Roebing Idea* coming into more general use since the

engineers, New York City, and was constructed under their direction. They were retained with the approval of the Province, the City and the Laurentide Company, by Fraser-Brace, Ltd. of Montreal, which concern built the



Fig. 20
Grand' Mere



Fig. 21—Dome

erection of the Dome Bridge, is fast growing in favor because of increased speed and economy in erection.

The Grand' Mere Bridge was designed by Robertson & Steinman, consulting

bridge under a lump contract. The Dome Bridge was designed by the Highway Department of the state of Arizona and erected by the Levy Construction Company.

Grand' Mere

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being 1207 feet
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Typical Small Suspension Bridges



1. Pipe Line—Multiple span with wind truss
3. Pipe Line—Single span with wind cables
5. Footwalk.

2. Highway
4. Conveyor

The

SMALL suspension bridges of ropes or cables, transverse between ships, been the method of crossing the Hellespont in Greece in 480 B.C. found to show tropical jungle fashioned crude using the twisted fibers nature so making their cr and ravines.

If primitive knowledge of the principles, and their application of material, they grasped the suspension bridge, the reason as to why the more generally effective idea to problems.

In considering the question, it is realized that in spite of design and erection associated with the bridge, there are where other types though the sus



Fig. 1—Section Every Th

The Small Suspension Bridge

SMALL suspension bridges fashioned of ropes on which beams were laid transversely and then suspended between ships, was supposed to have been the method Xerxes used in crossing the Hellespont during his invasion of Greece in 480 B.C. Evidence has been found to show that the natives of the tropical jungle countries oftentimes fashioned crude suspension bridges, by using the twisted vines and matted fibers nature so generously provided, in making their crossings over small rivers and ravines.

If primitive peoples, with their limited knowledge of the underlying principles, and their still more limited supply of material and equipment, so readily grasped the simple idea of the suspension bridge, the question naturally arises as to why the modern engineer does not more generally apply this simple and effective idea to present day small bridge problems.

In considering the answer to such a question, it is rather interesting to note, that in spite of the relative simplicity of design and erection which can really be associated with the small suspension bridge, there are a number of cases where other types have been used, although the suspension type may have

proven more economical. It certainly would have proven less difficult of design and erection, and surely more esthetically valuable.

Perhaps, however, the opinion happened to prevail that the cable analysis might be difficult and complicated as to its solution and handling during erection, thereby causing the suspension idea to be abandoned in favor of a more familiar idea. Such a prevailing opinion may have been caused by the fact that the technical schools and colleges have not in the past devoted very much time to the cable analysis of the suspension system; or possibly due to the fact that the theoretical curve of the unloaded main cables is viewed with a certain amount of apprehension because it happens to be a catenary. An accurate analysis of the catenary may be somewhat involved, but there are certain simpler formulas based on the parabola that can be easily applied with sufficient accuracy for the small suspension bridge. The parabolic formulas are not only simple in their application, but they can be very easily derived.

A number of the parabolic formulas relating to the loaded suspension bridge cable, are familiar to many, since they have been used for a number of years.

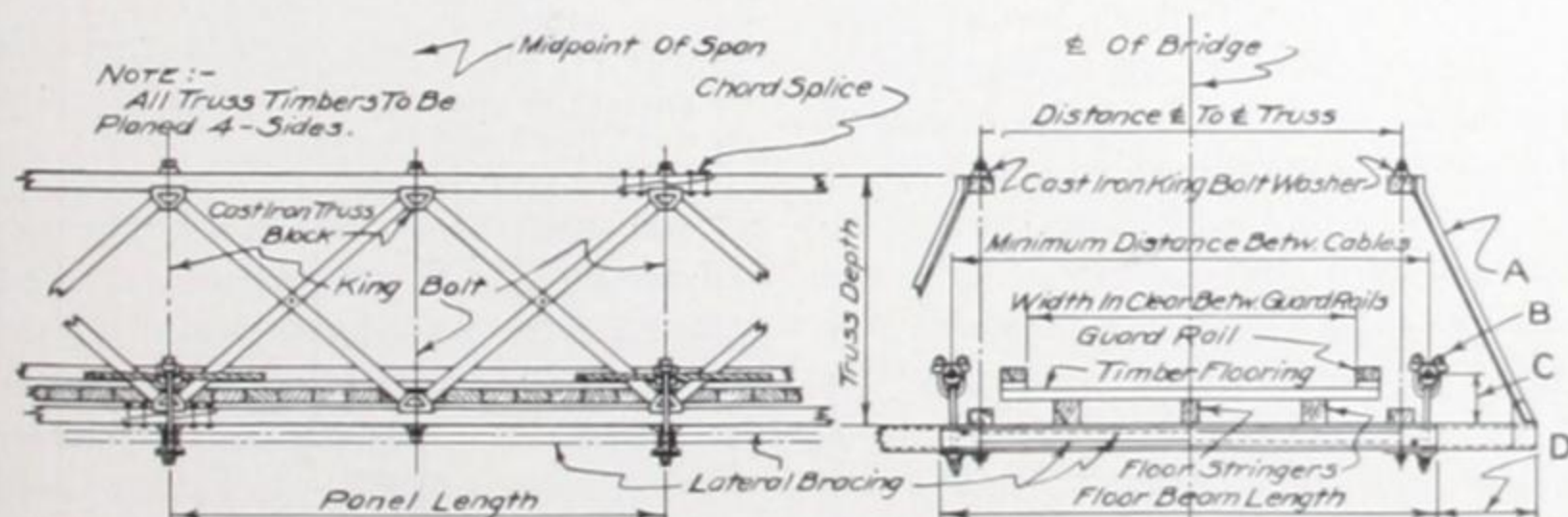


Fig. 1—Section of Light Suspension Bridge or Walkway a. Wind Bracing Angle at Every Third Floor Beam. b. Cable Clamp. c 12 in. (Minimum.) d. Extension of Floor Beam Channel for Wind Bracing Angle Connection

However, the data, formulas, and related equations which follow should enable the designer, builder or user of the small suspension bridge to make up the necessary preliminary calculations for determining the cable size and various quantities of material required, so that a comparative estimate can be made between the suspension type of bridge and any other type that may be contemplated for the location.

One might well ask, "what is considered a small suspension bridge?" The term "small" is meaningless and of no value except when used in comparison. The Brooklyn Bridge, for example, is a small suspension bridge when compared with the mammoth George Washington Bridge. The former however, was the engineering marvel of its time, and is ranked today as one of the world's great bridges.

Can we therefore, classify bridges generally according to their spans? If so, we should say that a walkway bridge with a span of 500 ft. is larger than a four-lane highway bridge with a span of 300 ft., which is, of course, absurd. On the other hand, a heavy pipeline bridge with 1000 ft. of span is certainly larger than a two-lane highway bridge having a span of 200 ft. Therefore, span alone is no measure of size.

Two guiding factors in determining the magnitude of a suspension bridge are: (1) The length of main span, (2) suspended dead load per linear foot of bridge. These two factors do not carry the same weight, and as a measure of magnitude we actually have the first power of the dead load multiplied by the square of the span—better recognized as WL^2 . This appears as a logical yardstick with which to measure the size of a suspension bridge. But WL^2 is directly reflected in the metallic area, or better still, the tensile strength of the main cables; so let us say that the criterion of size is the total tensile strength of the main cables.

Now, where is the dividing line between a small and a large suspension bridge? The answer to this question is purely arbitrary, but for practical purposes we will assume all bridges, the main cables of which have a total tensile strength of less than 1,600,000 lbs., as falling under the heading of small suspension bridges.

Classified according to their various uses, we have (a) the walkway or foot-bridge, (b) the light highway bridge, (c) industrial railroad bridge, (d) conveyor bridge, (e) the pipeline bridge.

The choice of the loadings to be used in designing a bridge should be given careful consideration, and is naturally governed by the particular location, conditions and requirements of the bridge. The maximum anticipated uniformly distributed live load, as well as any concentrated load that the bridge may have to carry, should be considered together with the wind, snow or ice loading produced.

Representative Suspended Dead Loads of Small Bridges	Pounds per Linear Foot Bridge			
	Wood (Based on 3 1/2 lb. per B. F.)	Steel	Misc. steel castings suspend- ers, etc.	*Total dead load
4 ft. walkway, no stiffening truss.....	45		8	53
6 ft. walkway with wooden stiffening truss.....	74		11	85
3 ft. all steel walk- way with stiffening truss.....		110	8	118
Single lane light highway with wooden stiffening truss.....	373	216	51	640

*The values given do not include the weight of the main suspension cables.

The amount of material required for the suspended floor system and for the towers, may be approximated by using certain conventional design methods. However, the towers should not be treated as simply statically loaded columns, and due consideration must be given to conditions resulting from un-uniformly distributed live loads, mov-

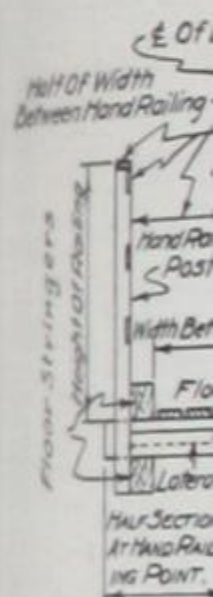
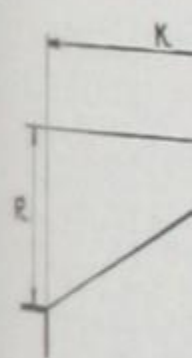


Fig. 2—Typical Section of a Suspension Bridge

truss, but on sufficient stiffening properly designed additional stringers. The amount of depends upon the



the structure. heavy moving should be designed; on the loaded bridges, conveyors, the omitted. Each considered in the requirements and finite design can

ing concentrated loads, temperature changes, longitudinal transverse winds, etc.

The suspension bridge is inherently a flexible structure, and in the majority of cases some form of stiffening must be incorporated in the design to insure sufficient rigidity to the floor system. This usually takes the form of a stiffening

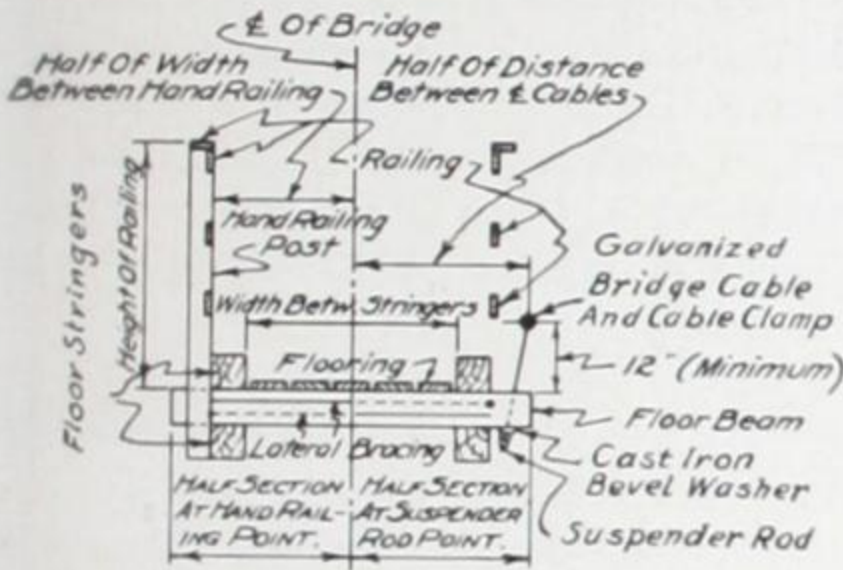


Fig. 2—Typical Section of Light Suspension Foot Bridge

truss, but on many walkway bridges sufficient stiffness may be obtained by a properly designed handrail system or by additional stringers in depth, or by both. The amount of stiffness required depends upon the utility requirements of

The effect of heavy transverse winds on a poorly designed suspension bridge might prove disastrous, and it is necessary to incorporate in the bridge a properly designed wind bracing system.

After the total dead and live loads have been determined, the cable analysis can be made with sufficient accuracy for the small bridge by applying the following formulas:

$$H_m = \frac{wl^2}{8d} \dots \dots \dots [1]$$

$$H_m = \frac{(wl + 2P)l}{8d} \dots \dots \dots [2]$$

Where H_m equals horizontal component of tension in pounds (this horizontal force is the same for any point of the curve); w equals total gross uniform load in pounds per linear foot of bridge; l equals horizontal span length in feet measured from tower to tower; d equals deflection or sag of main cables at mid-span in feet (the most economical ratio for suspension bridges has been found to be usually 10% and not less than 8% or more than 12% of the span). In equation No. 2, P equals total concentrated

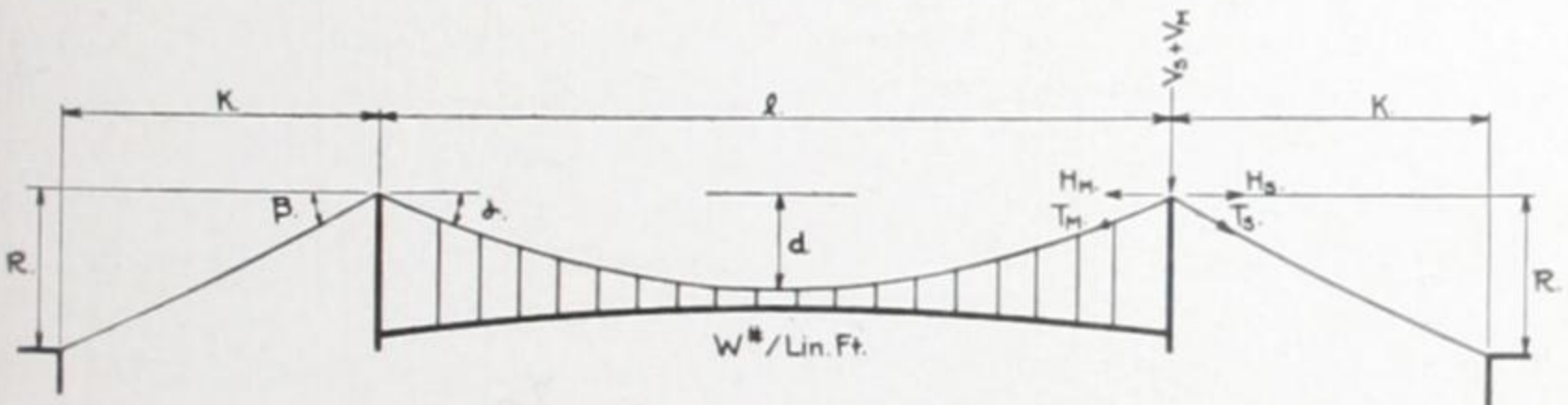


Fig. 3—Basic Dimensions for Parabolic Cable Analysis

the structure. All bridges subjected to heavy moving concentrated loads, should be designed with the stiffening truss; on the other hand, in statically loaded bridges, such as pipelines or belt conveyors, the stiffening truss may be omitted. Each bridge must be considered in the light of its particular requirements and location before a definite design can be adopted.

loads in pounds. From the vertical reaction equations,

$$V_m = \frac{wl}{2} \dots \dots \dots [3]$$

$$V_m = \frac{wl + P}{2} \dots \dots \dots [4]$$

the resultant tension—

$$T_m = \sqrt{V_m^2 + H_m^2} \dots \dots \dots [5]$$

can be obtained. Equation No. 2 considers concentrated load as being at mid-span only. The Tm tension in pounds thus obtained will not be the maximum tension in the cables, if the angle β is greater than angle α ; where α is the angle of the cable tangent at the tower points on the main span, β is the corresponding angle on the side span. The angle α is obtained from the relation:

$$\tan \alpha = \frac{4d}{l} \dots \dots \dots [6]$$

and—

$$\tan \beta = \frac{R}{K} \dots \dots \dots [7]$$

These values of R and K , shown on Fig. 3, are naturally governed by the most suitable anchorage location. The side span or back stay tension is then obtained from:

$$Ts = Hs \sec \beta \dots \dots \dots [8]$$

All of the formulas given are based on cables supported at the same elevation at both towers.

After a choice of cable size has been made, based on the maximum tension obtained, and allowing a reasonable safety factor, the main span length of cable can be calculated by the approximate formula—

$$L = l + \frac{8d^2}{3l} \dots \dots \dots [9]$$

Where L equals length from tower to tower along the curve in feet. The more accurate parabolic length is found by—

$$L = \frac{1}{2} \sqrt{16d^2 + l^2} + \frac{l^2}{8d} \log_e \left(\frac{4d + \sqrt{16d^2 + l^2}}{l} \right) \dots \dots \dots [10]$$

For the small bridge, however, the length value given by equation No. 9 has been found to be sufficiently accurate; particularly if the main cables have attached open or closed bridge sockets

which allow a length adjustment at each anchorage, such as illustrated by Figs. 4 and 5.

The back stay length can be found with sufficient accuracy by—

$$Ls = K \sec \beta \dots \dots \dots [11]$$

This equation can be applied for both conditions of loaded and unloaded side spans. The side span is considered as being loaded, if the floor system is extended from the tower to or near the anchorage, by being suspended from the main cable. The general profile of the bridge location usually determines the main span length, and also as to whether it is more economical to have the suspended side span, or what is commonly termed the unloaded straight back stay.

The relations of tension in the cable can be determined from the equations already given, provided the uniform load of the side span is not more than the total used for the main span calculations. This is usually the case, however, on the small bridge with suspended side spans, and it is very rare to have a change in load. In fact, the most general case encountered for the small bridge deals with unloaded back stays.

The suspender size is governed by the total load on each panel, and it is usually assumed that the two opposite suspenders at each point carry the entire load of the panel. The panel length is governed entirely by the most economical design of floor system, except possibly where stiffening trusses are to be included and the length of the panel is made suitable to the truss chosen. For the suspender on the small bridge, a rod, having a forged eye on one end and a threaded length at the other end, is frequently used.

It has been found, however, that in lengths of possibly twelve feet or more, a steel wire rope or strand suspender with attached fittings, or compressed terminals could be more satisfactorily used,

All Sockets
With The Use Of
Pure Zinc Spelter

Fig. 4.—Gal

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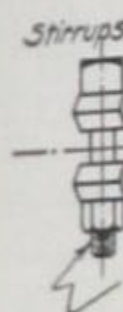


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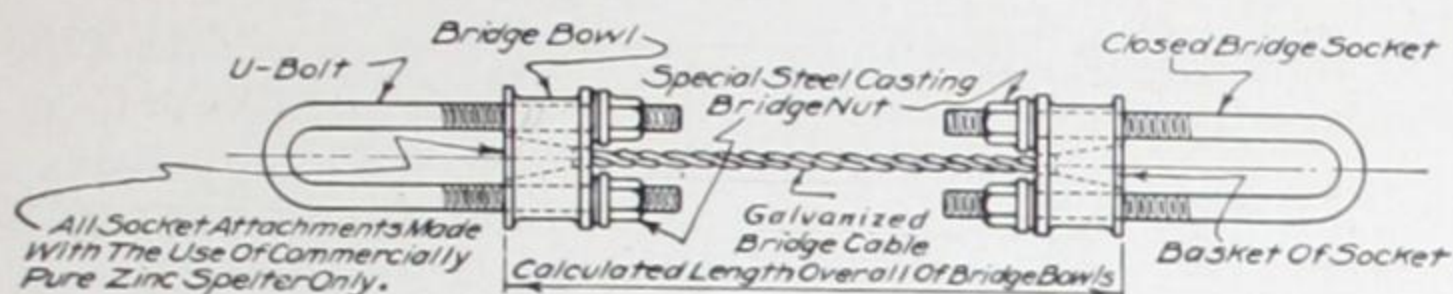


Fig. 4.—Galvanized Bridge Cable with Closed Bridge Socket attached to each end.

such as illustrated by Fig. 6. It can be seen that the eye bolt with plate or washer, provides a good connection for either a wooden floor beam or a pair of

span suspender in feet. The value of N should not be less than twelve inches, and is usually governed by the particular type and size of the bridge.

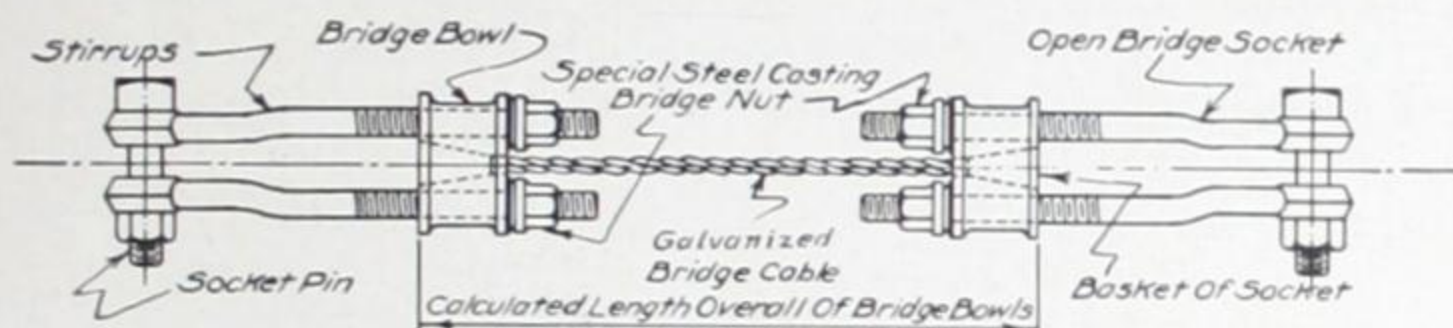


Fig. 5.—Galvanized Bridge Cable with Open Bridge Socket attached to each end.

steel channels as shown. An approximate estimate of the average length of suspenders required can be determined by—

$$S = .0337 l + N \quad [12]$$

(where the deflection is 10% of the span). S equals average length of suspender in feet; l equals main span in feet; N equals length of shortest or mid-

The connections of the suspender to the main supporting cable can be satisfactorily made by using a type of clamp such as shown on Figs. 6 and 7.

The main cable anchorage can be made by embedding anchor rods or steel plate bars in concrete such as illustrated in Fig. 8. The anchorage size, however, is necessarily based on the soil condi-

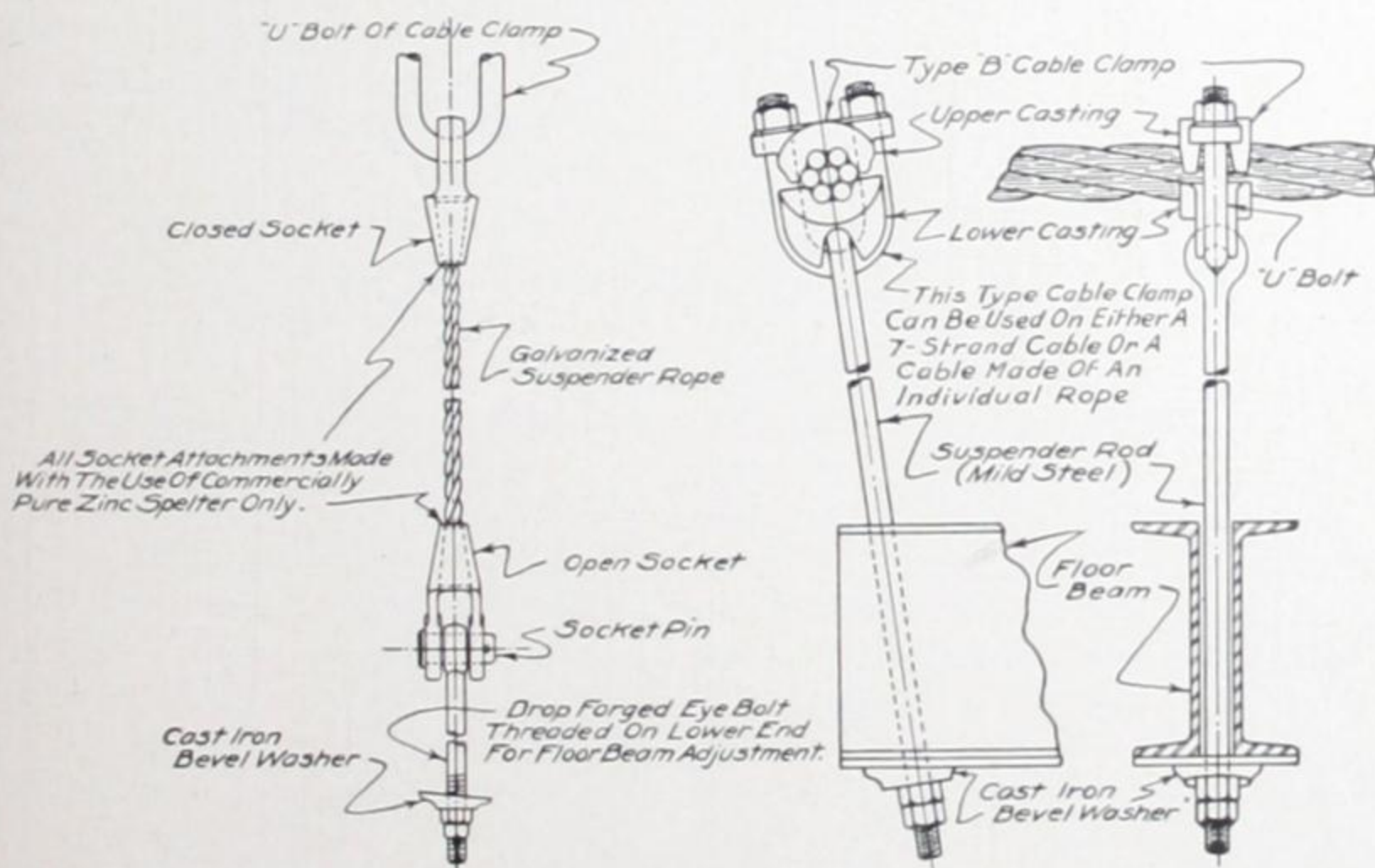


Fig. 6.—Typical Types of Suspenders

tions at the anchor point, as well as the cable tensions obtained.

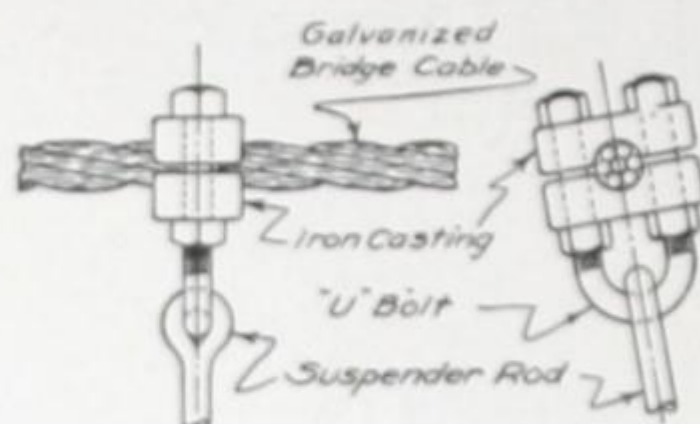


Fig. 7—Cable Clamp

The main cables should be properly supported by saddles where they pass

on the cable at either side of the saddle so as to prevent any slippage of the cables over the saddle castings. The type of saddle and the use of the tower clamps is more or less governed by the general design of the tower, as well as the length of the bridge span.

The formulas given should prove sufficiently accurate for designing and estimating purposes on small suspension bridges; however, there are other equations and formulas which should be used, if the most accurate analysis is required. The equations and informa-

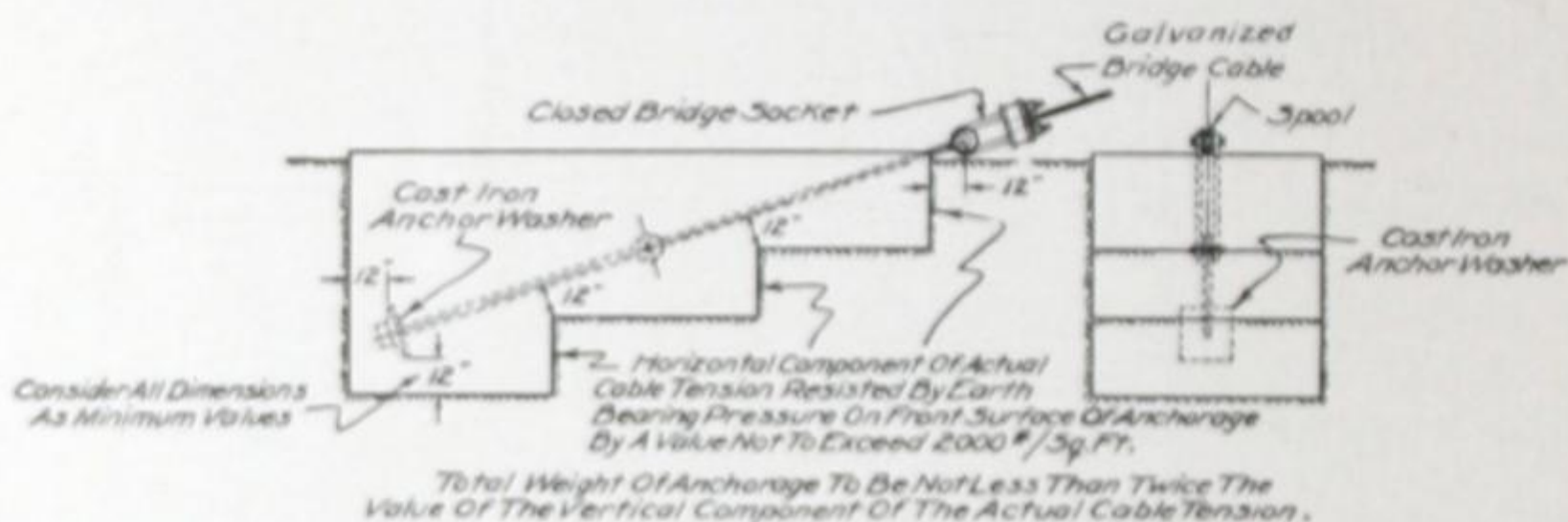


Fig. 8—Concrete Type Cable Anchorage

over the tower supports. If a flexible tower is used, clamps should be provided

tion given here are offered as an evidence of the simplicity of design.

Erection

IN a previous article on the fundamental principles of suspension bridge construction, it was pointed out that the erection of a suspension bridge is not too different from the erection of a truss bridge. It is just as simple.

The small suspension bridge previously classified as a "small" bridge having main cables of strength up to 100,000 pounds.

In considering the erection of a small highway suspension bridge, the following factors must be considered: (a) the anchorage (b) the cables (c) the suspension system.

Perhaps a better method of obtaining the actual construction of a bridge. There is a detailed illustration in Fig. 1 of this article.

In following the same method and the same equipment used in the construction of a bridge was supplied by a tractor running



Fig. 1—A Typical Small Highway Suspension Bridge

Erecting the Small Highway Bridge

IN a previous article on *The Small Suspension Bridge*, some simple fundamentals of design were pointed out indicating that a suspension bridge is not the complicated structure that it is generally supposed to be. In the present article it will be shown that the erection of a small suspension bridge is just as simple as the design.

The small suspension bridge has been previously classified as being a bridge having main cables with a total tensile strength up to and including 1,600,000 pounds.

In considering the erection of the small highway suspension bridge, the structure can be conveniently divided into the following main parts: (a) anchorages (b) piers (c) towers (d) main cables (e) suspenders (f) trusses (g) floor-system.

Perhaps a better conception would be obtained by following in general the actual construction of a small highway bridge. Therefore, the bridge as illustrated in Fig. 1 is selected as the basis of this article.

In following the construction keep in mind the simplicity of the erection equipment used. The little power required was supplied by an ordinary farm tractor running along the road, and to

which was attached the end of the hoisting rope. Two gin poles picked up conveniently at the location, were used in setting towers and hoisting the main cables. All other material, steel and timber, was readily handled into position by the erection gang. This gang of bridge men was recruited wholly from local labor, and except for the supervision, *no previous experience* was required.

The bridge has a main span of 170 feet with a width of roadway of eleven feet. It was designed to safely carry the concentrated load produced by a 15-ton loaded truck at mid-span plus 25% impact. A wind-snow-and-ice load also was considered in the choice of the size of members. Each of the two main cables consists of one 2-in diameter galvanized bridge cable supported by steel-casting saddles mounted on steel towers which in turn rest on concrete piers. The cables are continuous in length from anchorage to anchorage, and extend as straight backstays 90 feet and 91 feet, horizontal distances respectively, beyond each tower. The anchorages are concrete blocks in which are embedded the anchorage steel designed to take the main-cable fitting or socket connection.

The main cables have a mid-span loaded sag or deflection of 26 feet. The bridge design includes two wooden stiffening trusses and the floor-system, with steel supporting members and wooden roadway floor, has a camber or vertical rise of one foot, seven inches, at mid-span. The cables are given a cradle or horizontal deflection at mid-span of



Fig. 2—Gin-pole used for erecting Tower is now hoisting Main Cable into Saddle

one foot, three inches, so as to give additional rigidity against windage action.

The blocks of concrete for the anchorages are placed according to modern practice, with care taken to properly place the reinforcing steel required, and also setting the anchorage steel so that the specified head locations are obtained.

The profile of the site, the space available and the soil formation, as well as the various loads all necessarily determine the size, shape and location of the anchorages. In the particular bridge

example we have chosen, it can be seen that it was necessary to locate one of the anchorages slightly higher up on the slope in order to provide clearance for an existing highway.

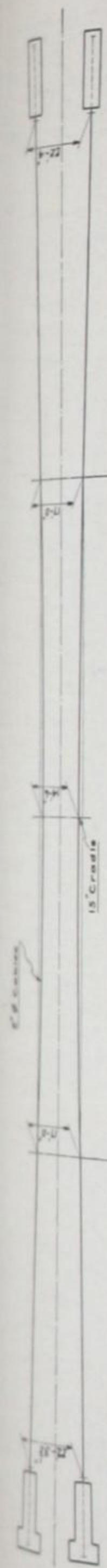
Excavations are made for the tower piers until a suitable foundation is reached. On this particular bridge, and on most of the smaller bridges, these piers are so located as not to require any special equipment, or undue difficulties in making the excavations. The tower foundation bolts are set as the concrete is poured. A 1: 2: 4 mix is generally used on the piers as well as the anchorages.

After a reasonable length of time is allowed for proper curing of the tower pier and anchorage concrete, the towers are erected—see Fig. 2. Since the weight and length of the steel tower legs are not excessive on the smaller bridge, they are shipped as one piece. The tower legs can either be erected separately and later connected together by the bracing, or the whole tower can be assembled and raised at one time. The towers in question were erected by means of gin-poles mounted on the piers.

The saddle castings may be bolted to the tower top, either before or after the latter is erected, depending upon weights and the rigging available.

There are two general methods commonly used in the erection of the main cables. In the example bridge shown, (Fig. 2) the 2-in.-diameter cables were laid out across the river and extended from anchorage to anchorage. A bight of the cable was then hoisted at each tower and placed in the saddles, the ends of the cables having previously been connected to the anchorages. The gin-pole and tackle used in erecting the towers of the bridge were also used to hoist the cables to the tower tops and place them in the saddles.

Another method sometimes used is that of pulling the cables from one



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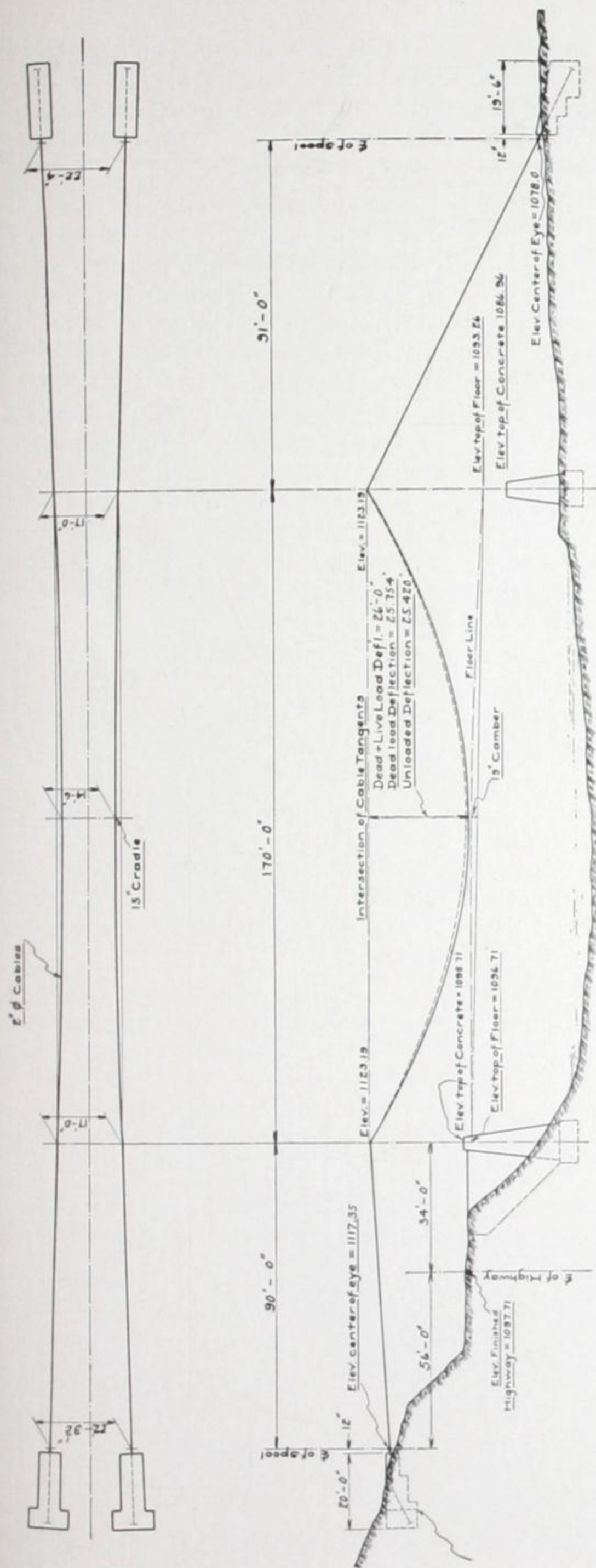


Fig. 3—Working drawing giving principal dimensions governing cable erection and adjustment



Fig. 4—Diagram showing how chord splices are staggered

anchorage up over the towers and down to the opposite anchorage. In this method a pulling-or tag-line equal to the length of the cable is required and care must be taken to prevent any injury to the main cables as they are being pulled through the saddles. Wooden rollers or blocks can be used to prevent any such injury to the galvanized surface of the cables. Care should also be taken to prevent the cables from being suddenly released at the reeling end, and a snubbing line with a suitable clamp should be provided.

The first mentioned method is simpler and safer and is recommended whenever circumstances permit. The fact that both ends of the main cable are anchored before tension is applied guards against the possibility of "runaway" ends.

The reels on which the main cables are furnished should be properly mounted so that they will rotate while the cable is "paying off", or if space is available, the cable can be unreeling by rolling the reel along the ground. In either method of unreeling, the cable should be protected so as to prevent any possible injury or abuse to the individual wires and the galvanizing. If the cable is unreeling by rotation, a brake should be provided to insure smooth and even unreeling. A strong piece of timber placed as a lever under the reel flange will serve such a purpose.

The cables are adjusted first to their correct mid-span sag by varying the length adjustment provided in the attached bridge sockets at the anchorage connection while at the same time working them through the saddles. The cable deflection should be checked with transit or level, if possible. However, if instruments are not available an ordinary carpenter's level can be used to obtain a fairly accurate deflection, by mounting the level in the tower at a distance below the center line of saddle equal to the *no-load* deflection of the cable. When the line of sight, with the

eye placed in line and immediately behind the level, coincides with the centerline of the main cable at mid-span the cable can be considered as having the proper deflection.

The importance of obtaining the correct *no-load deflection* of the main cables cannot be emphasized too strongly. A little carelessness here might result in inability to close, or to properly align, the truss system under full dead-load conditions. The *no-load* cable deflection should be accurately calculated previously to, and rigidly established during erection. Another consideration of prime importance at this junction, is tower position during cable adjustment. The towers may, or may not, be vertical at this time depending upon several governing factors. However, the correct tower position should be pre-calculated and this position held during cable adjustment. A plumb line from tower-top to tower-base is a simple and effective means of determining tower-position.

When proper adjustment has been secured in main and side-spans, cable clamps are placed on the cables on each side of the saddle to preclude the possibility of slippage during subsequent erection.

The erection of the cable bands and suspenders can be carried on at the same time as the erection of the floor beams and stringers. In some cases, however, all of the suspenders and cable bands are erected before any of the floor system is placed.

In using either method the erection should proceed simultaneously from each tower, or in a few special instances, starting from mid-span and proceeding simultaneously toward each tower. This procedure of balanced load is very important so as not to cause any appreciable unbalance of tension and load on either the towers or cables.

Tower bending should be watched constantly during the erection of the suspended system and the predetermin-

ed maximum sag should never be

The spacing of smaller bridges, are not previous should be made of the actual cable bands. It is g cable-bands posi on the cables at measured for co manufacture. T be set out of pos their final elevat the final adjustm found to be mu bands slightly c would be to mo This suggested while. Ordinari equal in length horizontal panel this template gi that is slightly positions of the

In order to suspenders, a w arrangement si chair can be used mounted on the platform hung sheave is allowe as a track being



ed maximum safe bending of the tower should never be exceeded.

The spacing of the cable-bands on the smaller bridges, when the band points are not previously marked on the cable, should be made according to the horizontal dimensions without considering the actual cable curve lengths between bands. It is good practice to mark cable-bands positions and saddle points on the cables at the time they are being measured for correct lengths at place of manufacture. The cable-bands should be set out of position and slightly above their final elevation on the cable. When the final adjustments are made it will be found to be much easier to move the bands slightly down the cable than it would be to move them up the cable. This suggested hint will prove worth while. Ordinarily a template is made equal in length to the length of the horizontal panel spacing, and the use of this template gives a temporary setting that is slightly in advance of the final positions of the cable-bands.

In order to place cable-bands and suspenders, a working platform, or an arrangement similar to a boatswain chair can be used. Generally a sheave is mounted on the main cable and the platform hung from a sheave. The sheave is allowed to travel on the cable as a track being controlled by a connect-

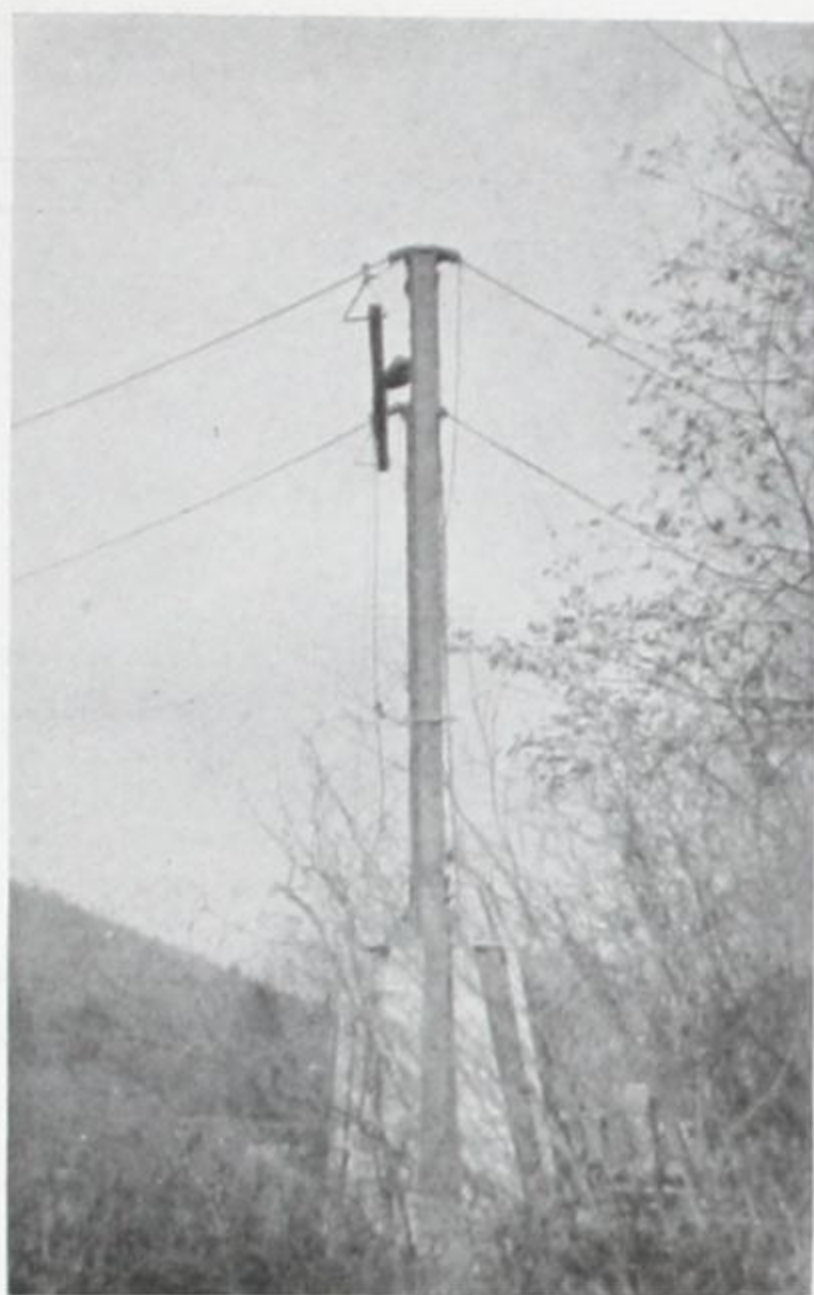


Fig. 5—Cables adjusted and clamped at tower saddles. Erection carriage in place and ready for placing cable bands and suspenders

ing rope extending back to the tower. Men working on this travelling carriage can then proceed out along the main cable curve, measuring spacings and placing cable-bands and suspenders until they are met amid-span by the workmen from the opposite side. (See Figs.

7, 8 and 9). This method is ordinarily used regardless of whether or not the floor system is erected at the same time as the suspenders.

On the bridge example chosen, the stringers and floor-beams were erected as the erec-



Fig. 6—Floor-steel erection proceeding from each tower toward mid-span.

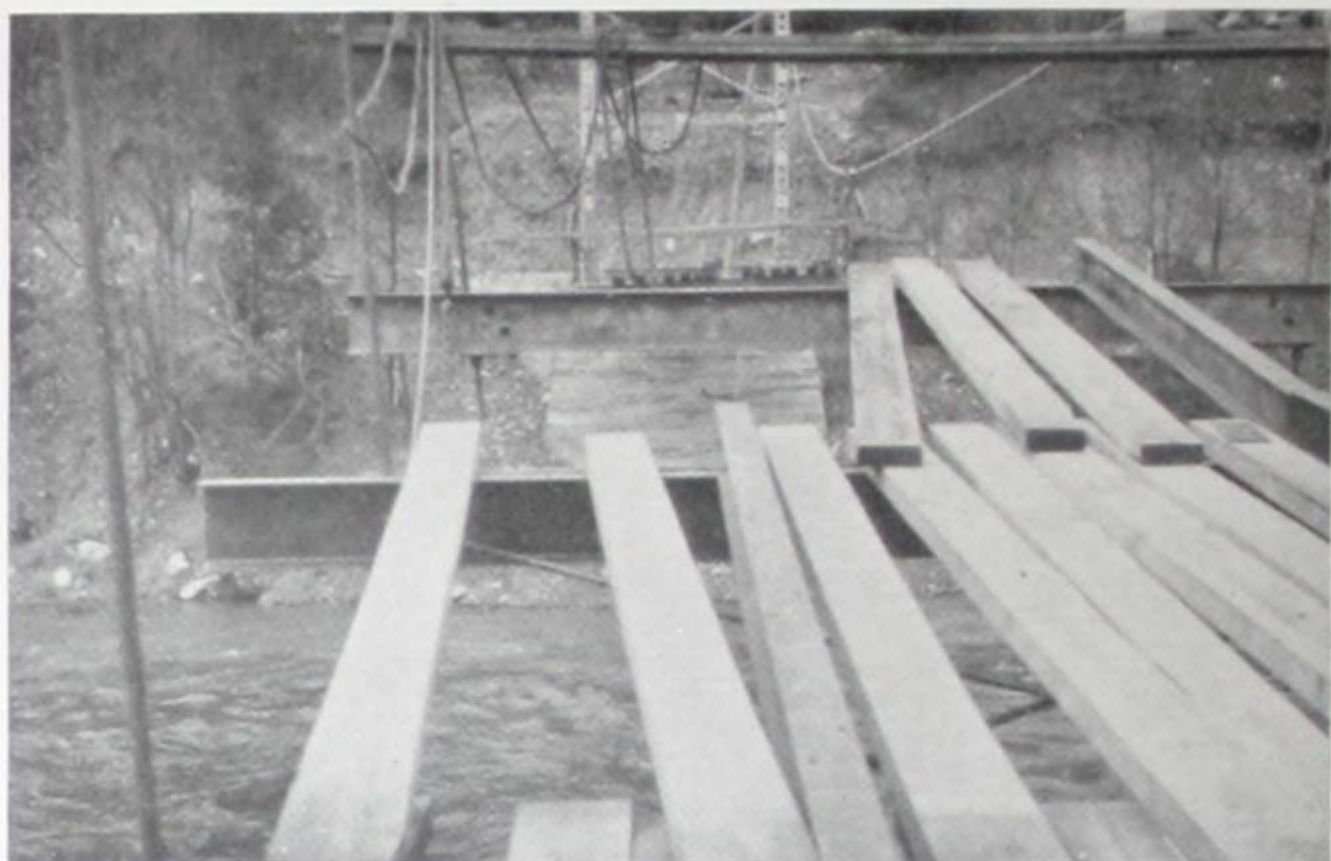


Fig. 7—Floor-beams, stringers and diagonals during erection. Floor planking used for working platform.

tion of the suspenders proceeded. Platforms of planks extending from one floor beam to the next point were used, each floor-beam being carried out over this temporary platform to its position. The cable working platform consisted in this case, of a heavy plank extending the entire width between cables and supported by bent steel frames which in turn were connected to travelling sheaves mounted on each cable.

The stiffening trusses are sometimes designed to take the suspender connection directly. However, on the small bridge this connection is generally made to the floor-beam. The wooden-type of stiffening truss employed on the smaller bridges is usually made essentially in accordance with the design shown.

In erecting the suspended system the deformation of the cable curve under the concentrated loads causes the partially erected bridge to assume all sorts of

Fig. 8—Progression of erection, showing natural distortion of cables and suspension system resulting from un-uniform loading.



weird shapes, (see Fig. 8). However, when the uniformly distributed dead load is all hung, the cables and the floor system return to their proper respective curves.

The wooden trusses (Figs. 10 and 11) are erected

after placing the suspenders, stringers, and floor beams, by starting at each tower simultaneously and proceeding toward mid-span. The truss joints near the center points cannot be finally tightened until the truss has been entirely closed at the center. As the truss is erected a *hump* or rise in the truss chord elevation will be observed. This *hump* or rise of the chord reaches its maximum height at mid-span and it should not entirely settle down to a smooth curve until the full dead-load has been put on the bridge. By placing the full dead-load on the structure before closing the truss no difficulty should be experienced in truss alignment.

In the adjustment method must be suspenders will to the load. Start proceeding toward bridge simultaneously are adjusted to floor elevation and trusses will tend equal adjustment to check the b surveying instrument low the suspender load which is assumed equally throughout bridge.

Individual adjustment



Fig. 7—Floor-beams, stringers and diagonals during erection. Floor planking used for working platform.

weird shapes, (see Fig. 8). However, when the uniformly distributed dead load is all hung, the cables and the floor system return to their proper respective curves.

The wooden trusses (Figs. 10 and 11) are erected by suspenders, stringers, by starting at one end and proceeding toward the center of the bridge simultaneously, all suspenders are adjusted to give the predetermined floor elevation and bridge camber. The trusses will tend to be distorted if unequal adjustment is made and it is well to check the bridge roadway with a surveying instrument. This should allow the suspenders to take their proper load which is assumed to be distributed equally throughout the length of the bridge.

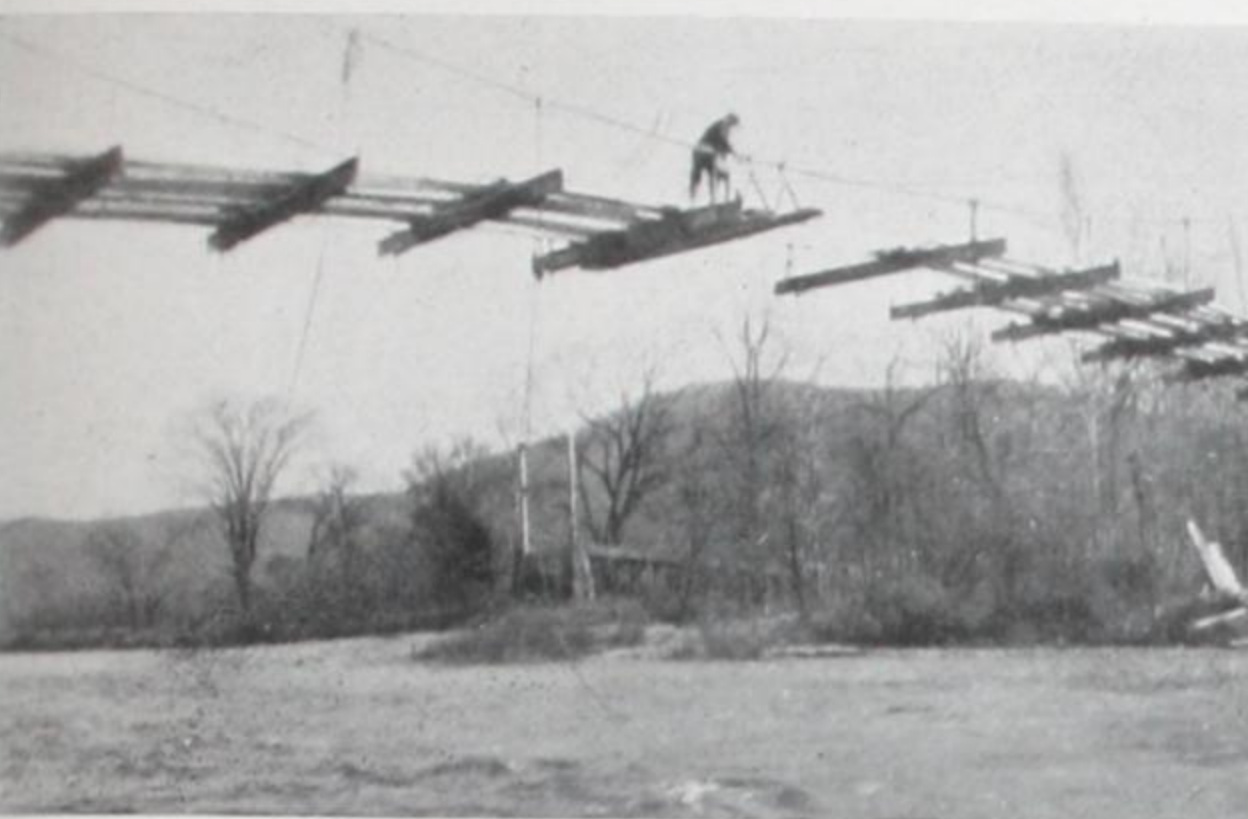


Fig. 9—Floor system about to meet at mid-span.

is usually provided for in the form of a threaded connection through the floor-beams. It is well to set the suspenders initially with an equal amount of thread at each connection. To proceed otherwise will result in readjustment difficulties which might well prove annoying in ironing out.

When the final dead-load, including the floor, has been placed upon the bridge, the truss should close without difficulty and form a smooth curve from tower to tower. Not until this condition has been attained should the truss system be finally tightened.

Although the erection, in itself, of the small suspension bridge is simple, it is not to be assumed that certain fundamental requirements can be neglected without coming to grief. In the first place, certain careful calculating, meas-

Individual adjustment of suspenders

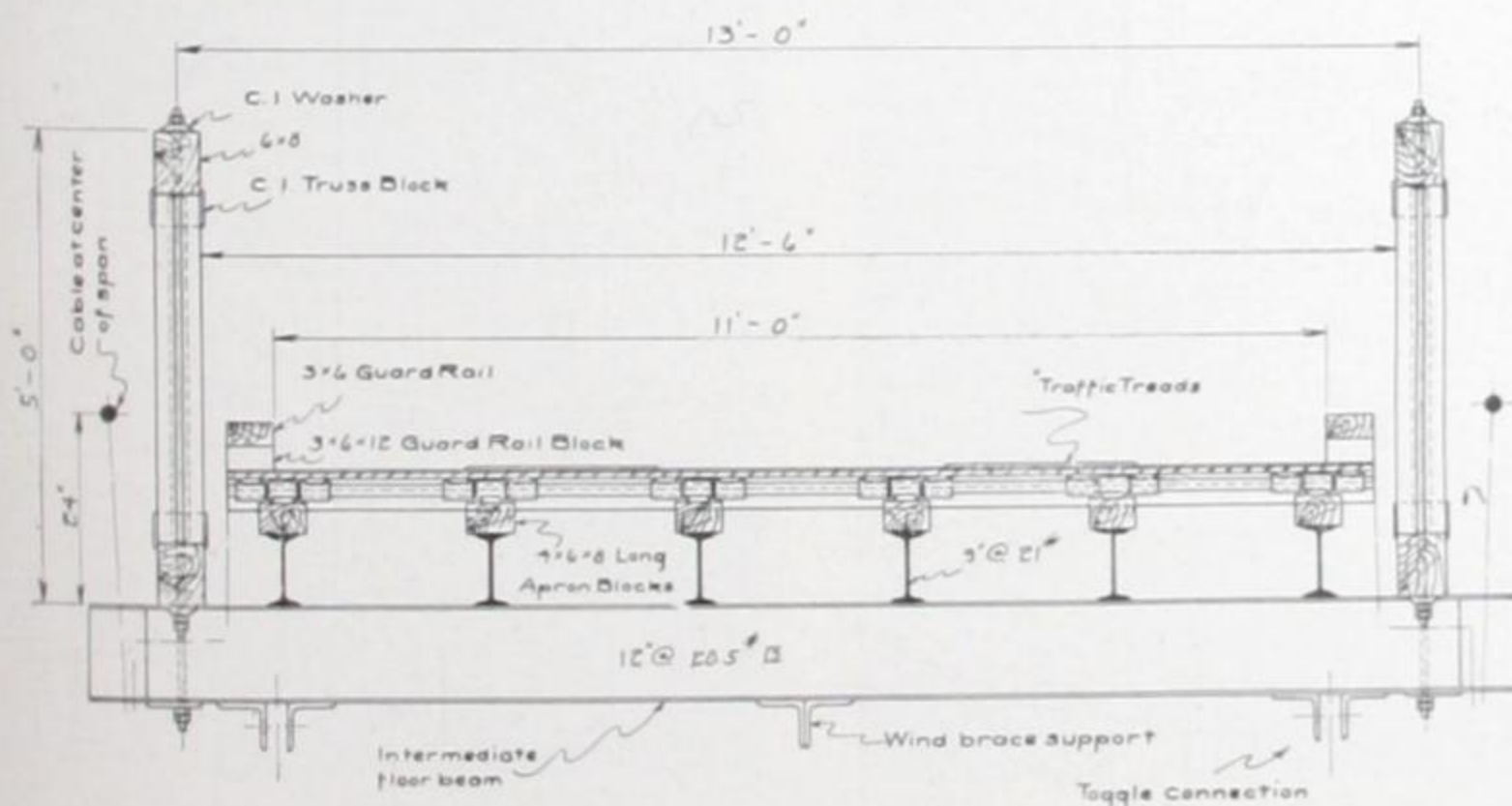


Fig. 10—Cross section of floor system and trusses.

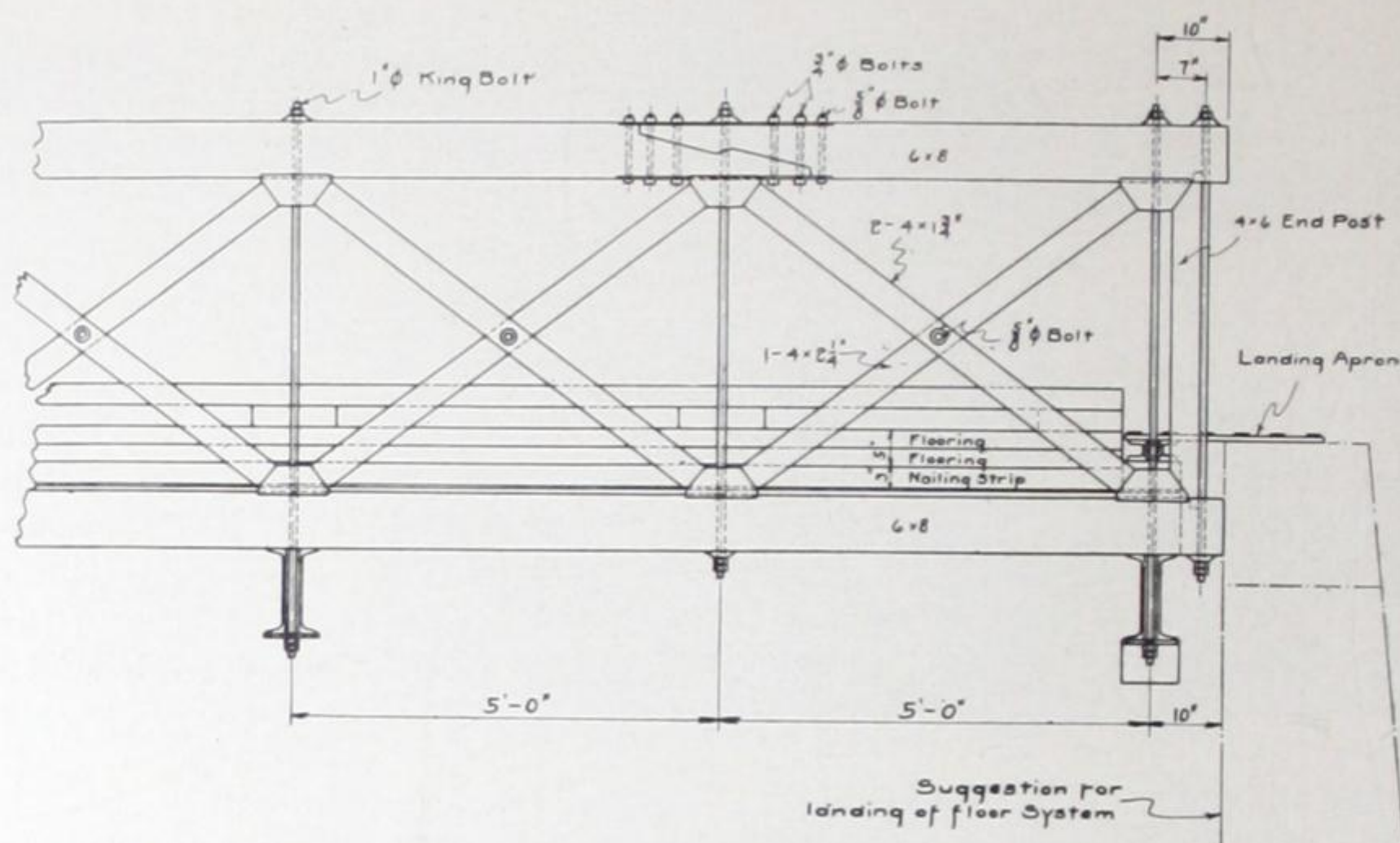


Fig. 11—Elevation of truss. Note typical timber splice in upper chord.

uring and marking are required; secondly, close supervision must be exercised during erection to see that the foregoing efforts are properly applied. It is the planning and supervision that count.

Properly supervised the greenest sort of crew with the meagerest amount of equipment, can erect a small suspension bridge quickly, economically, and most satisfactorily.



Fig. 12—Close-up of finished truss.

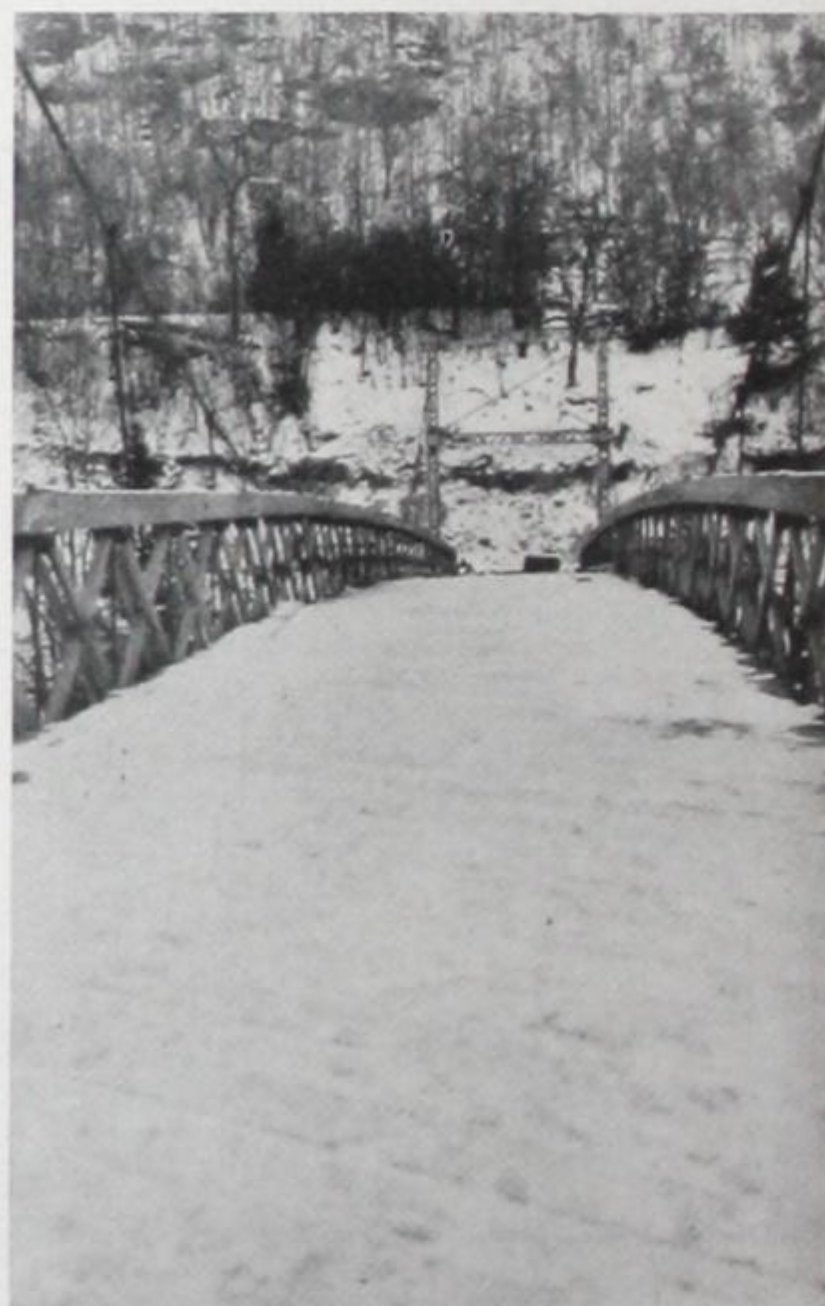


Fig. 13—Deck laid and trusses closed. Note smooth curve of trusses.

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How "Big" is a Bridge?

The Cable—key to bigness; nearly two million and a half tests on the George Washington cables—a builder of confidence in bigger and bigger suspension bridges

HOW "big" is a bridge?—that depends on the "measuring stick".

Some say the Golden Gate will be the biggest; others say the George Washington will still hold its first place in suspension bridges. For the third place the Ambassador and the Delaware vie for competition, while for the fourth place, the Delaware, Brooklyn and Manhattan bridges are contestants.

Bigness in suspension bridges, therefore, is a matter of the factors picked for the measuring.

Suspension bridges are "built-to-order"—built to meet local traffic conditions, present and future, and every such bridge is a designing and constructing problem unto itself. A problem for the traffic, bridge and cable engineers, the geologist and financier to solve.

With the historical Brooklyn bridge as a starting point in big suspension bridges, each bridge since then has been built big to meet some local traffic condition—bigger than the previously existing traffic-moving facilities, and a look into the future for how much bigger to build to meet expected traffic requirements. But, what is bigness in suspension bridges?

(1) If we take the popular conception—"length-of-span", as our measuring stick, the new Golden Gate bridge takes first place, with its 4200-ft. main-span and its total length of each cable 7694 feet, anchorage to anchorage—(*Graph B*) page 104. To the cable manufacturer it means a far different problem than a shorter main-span with a heavier load to carry, as is the case

with the George Washington bridge, in second place, with a 3500-foot main-span and 5212 feet as a cable length anchorage to anchorage.

(2) If we take "diameter-of-cables" (*Graph C*) page 104, as the unit of measurements of bigness, the Golden Gate, with its $36\frac{1}{2}$ in. diameter cables as compared with 36 in. for the George Washington it is still the biggest.

(3) But "length-of-main-span" and "diameter-of-cable" are only a part of the picture of bigness.

(4) To express "size" in terms of "total-strength-of-cable" (*Graph D*) page 106, gives a more complete idea-picture in comparative bigness, for in such terminology is included the requirements of not only length, but width, traffic requirements, and additional lanes or decks, for future needs.

Then, let us look at the most prominent elements of the accompanying picture of the George Washington bridge—the four massive parallel wire cables—built for a total strength of 350,000 tons (or 87,500 tons per cable) to meet the heavy traffic-demands of today, and a look into the future requirements in one of the most thickly settled areas of the world, therefore, a study of *Graph D* in comparison with *Graphs B* and *C* enables us to better appreciate the bigness of these two superior-span structures, and the relative position of the other eight in this group of big bridges. The ten bridges with cable-strength of 25,000 tons and over have been selected for this comparison.



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*The Four Massive Cables of the George Washington Bridge.
How "BIG" is a Bridge? Is the Cable the Unit of Measure?*

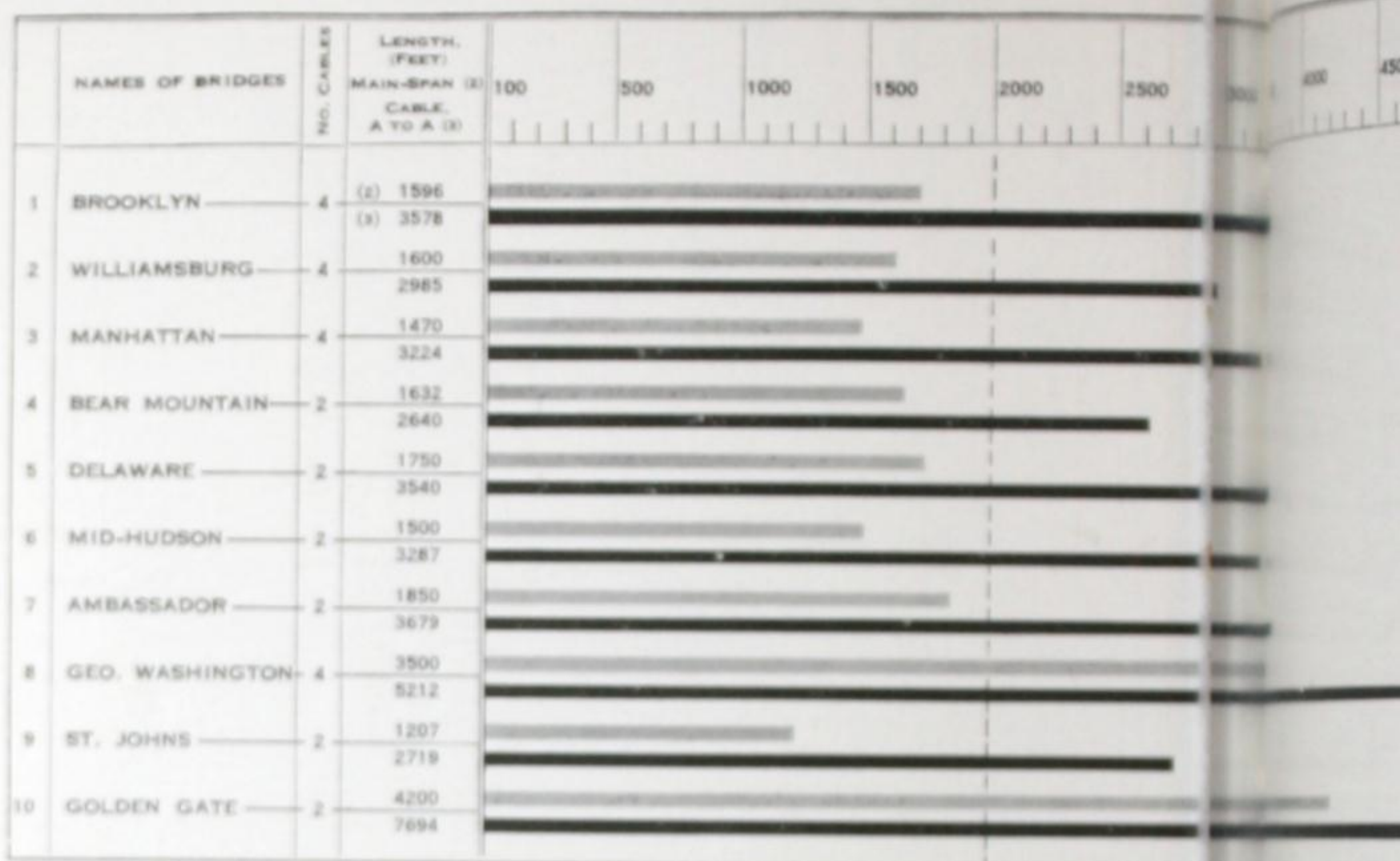
TABLE A—COMPARING THE "BIG" SUSPENSION BRIDGES

NAMES OF BRIDGES	LENGTH MAIN-SPAN FEET	LENGTH CABLE A TO A (1) FEET	NUMBER AND DIAMETER CABLES INCHES	TOTAL STRENGTH ALL CABLES TONS	STRENGTH PER CABLE TONS
NOTE 3					

TABLE A—COMPARING THE “BIG” SUSPENSION BRIDGES

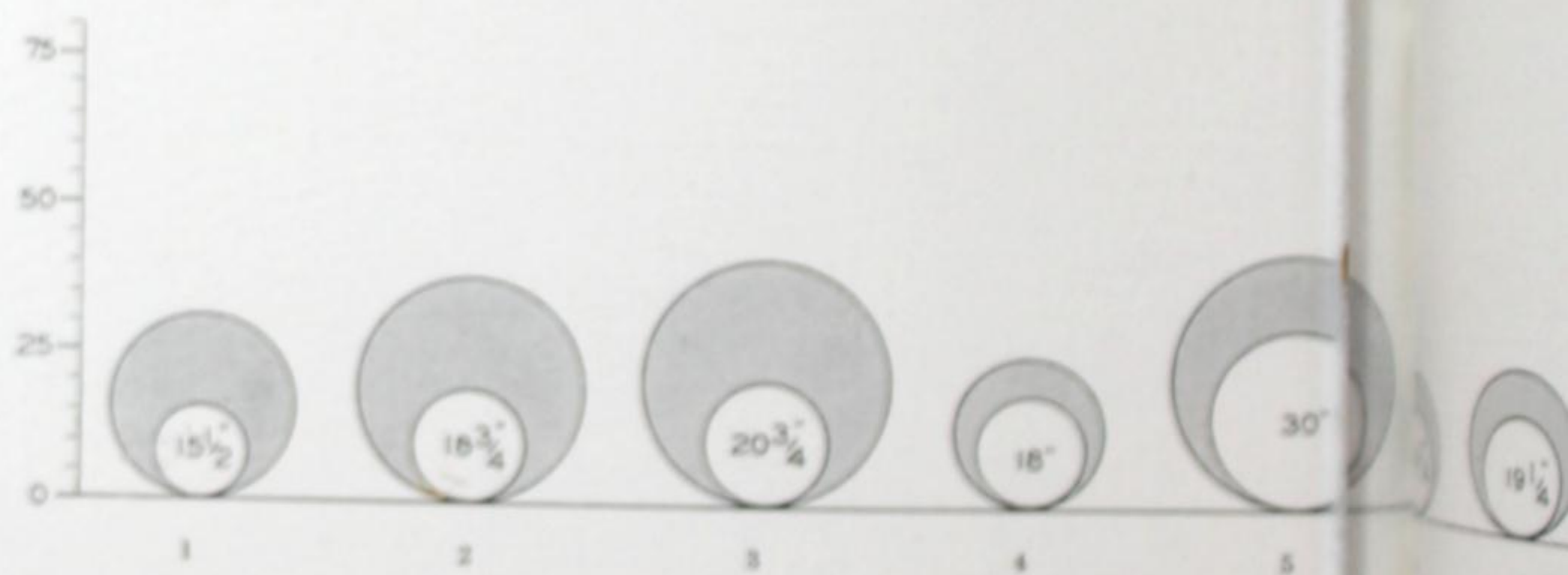
NOTE 3	NAMES OF BRIDGES	LENGTH MAIN-SPAN FEET		LENGTH CABLE A TO A (1) FEET		NUMBER AND DIAMETER CABLES INCHES		TOTAL STRENGTH ALL CABLES TONS		STRENGTH PER CABLE TONS	
		(4)	a	(4)	b	(4)		(4)		(4)	
10	GOLDEN GATE	1	4200	1	7694	1	2—36.5	2	193004	1	96502
8	GEO. WASHINGTON	2	3500	2	5212	2	4—36	1	350000	2	87500
7	AMBASSADOR	3	1850	3	3679	5	2—19.25	6	53500	5	26750
5	DELAWARE	4	1750	5	3540	3	2—30	3	118000	3	59000
4	BEAR MOUNTAIN	5	1632	10	2640	7	2—18	7	47200	7	23600
2	WILLIAMSBURG	6	1601	8	2985	6	4—18.75	5	89200	6	22300
1	BROOKLYN	7	1596	4	3578	10	4—15.5	8	44800	10	11200
6	MID-HUDSON	8	1500	6	3278	8	2—16.75	9	39000	8	14500
3	MANHATTAN	9	1470	7	3224	4	4—20	4	113200	4	33300
9	ST. JOHNS (2)	10	1207	9	2719	9	2—16.5	10	25000	9	12500
	SEE GRAPH	B		B		C		D		D	

- (1) A to A—Anchorage to Anchorage.
 (2) Prestressed Parallel Strand Cable—All other Bridges listed are of Parallel Wire Construction.
 (3) Indicates rotation of erection—see Graphs B and D.
 (4) The italic figures indicate numerical relation of size as shown in the column to the right.



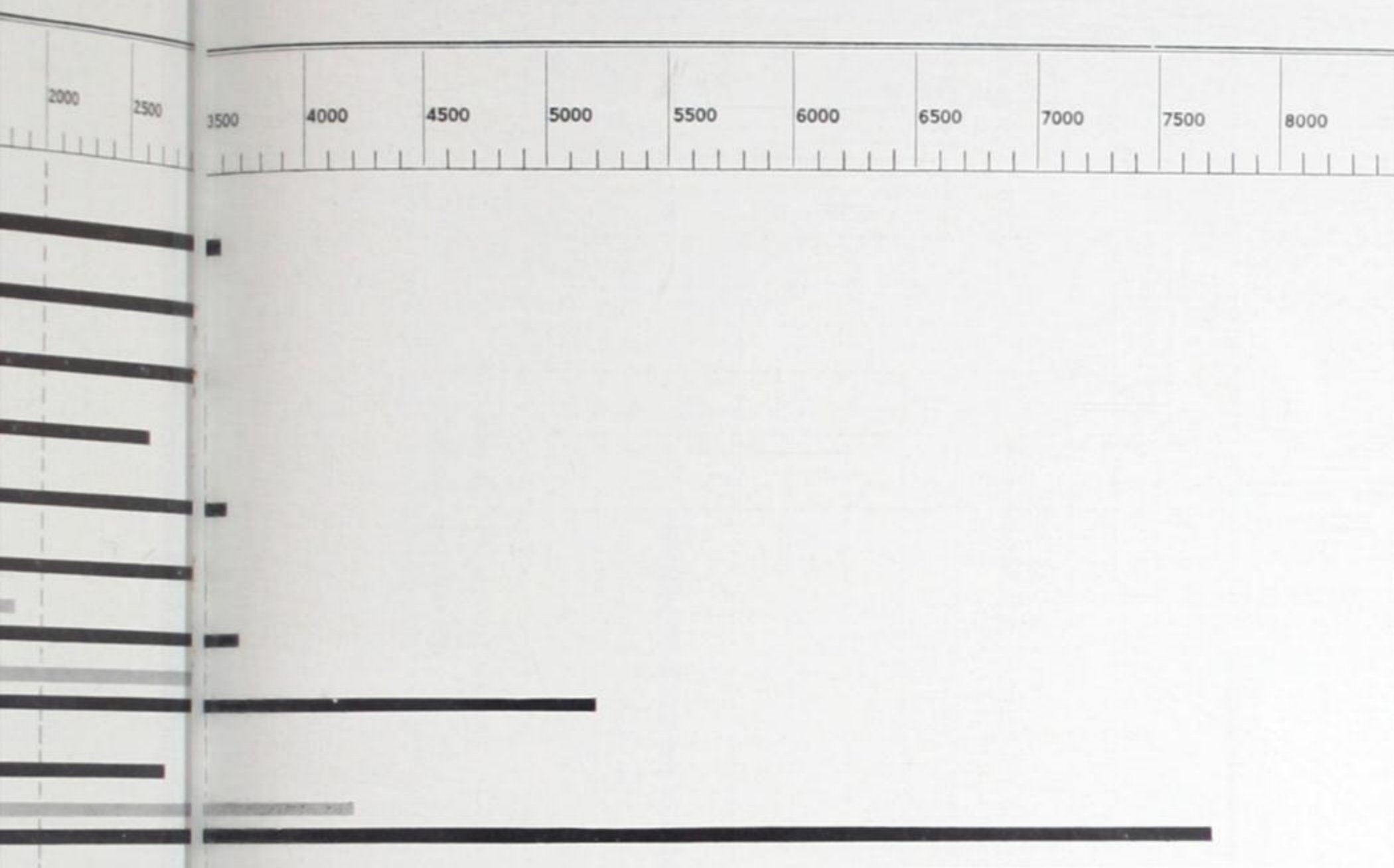
GRAPH B—Comparing the "Big" Suspension Bridges by Length of Main Span

(1) Listed in rotation of erection. (2) Top figure and top light shaded line indicates length of main span. (3) Bottom figure



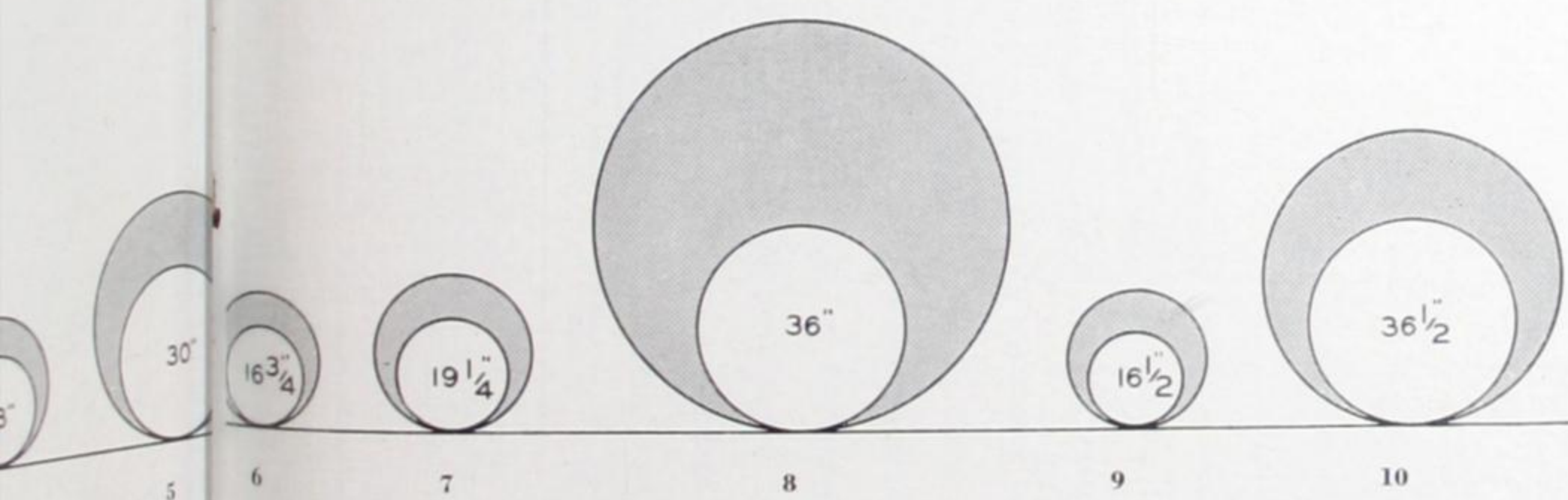
See GRAPH B for names of Bridges.

GRAPH C—Comparing the "Big" Suspension Bridges by Diameter

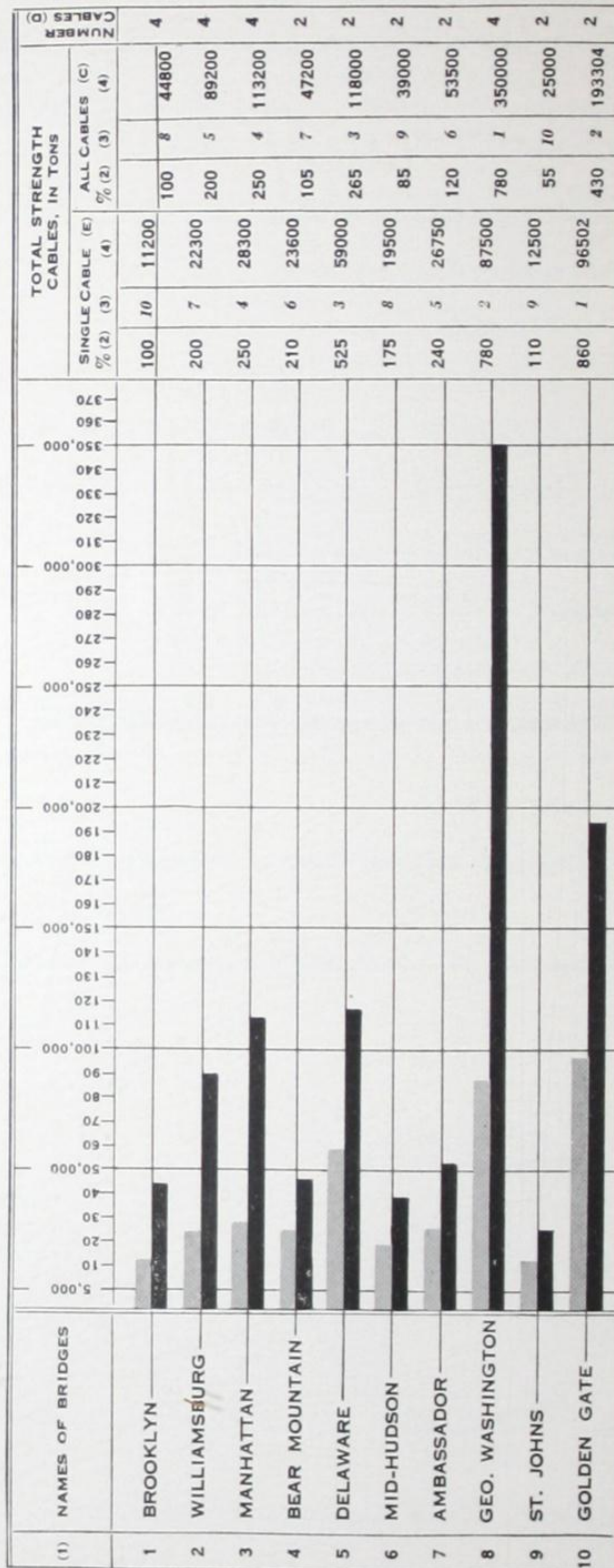


g the "Big" Suspension by Length of Main Span and Length of Cable.

line indicates length of main span. (3) Bottom figure and bottom black line indicate length of cable from anchorage to anchorage.



C—Comparing the Suspension Bridges by Diameter of Single Cables and Total Area of All Cables.



GRAPH D—Comparing the "Big" Suspension Bridges by Strength of Cables.

(1) Listed in rotation of erection. (2) Percentage of "bigness" comparing (E) single cables and (C) total strength of all cables on the bridge. (3) Italic numbers indicate numerical rotation according to strength of single cable (E) and all cables (C). (4) Top shaded line in graph indicates strength of (E) single cable, (C) the black line, all cables.

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So our conception of bigness depends upon what elements of the picture we select for comparison (*Graphs B, C, D*). Studying Table A, page 103, we find some of the reasons for the diversified opinion of the bigness of the six bridges referred to in the opening paragraph of this article, and we see a changing of places as we consider them from different viewpoints. With “length-of-span” for our yard stick (*Table A, column a*) the Ambassador bridge takes third place, and remains there when “total-length-of-cable” is considered (*Table A, column b*), but when total “strength-of-cable” (all cables or a single cable) is taken as the measuring unit, it drops to sixth and fifth places, respectively, and the Delaware River bridge, becomes third among the biggest and old Manhattan moves up from ninth to fourth place.

Bigness, therefore, is best measured in “cable-strength” whether we consider the total strength of all the cables in the bridge as the unit, or a single cable.

As this appreciation of bigness grips our imagination and we realize that wires of less than $1/5$ of an inch (.195 in.) are the supporting medium, it is not surprising for many to wonder what kind of wire was used, and is being used, to carry such increasing loads that represent an increase to approximately 860 percent in bigness, in terms of cable-strength, from the building of the Brooklyn bridge to that of the George Washington and Golden Gate bridges. To say that the wire, built up wire-by-wire to cable diameters of 30 in. to 36 in., as illustrated in Graph C, is made of acid open-hearth steel, means little to the average “bridge-user”, but when we realize that it is this “acid steel”—an expensive grade of steel—that continues to be used with such success and safety, there is built up in the public mind a feeling of confidence in this steel for bridges.

It is rather significant, too, that bridges of this group are all acid-steel cabled.

The “reason” is too long for discussion here, so let us leave the “why” to the metallurgist and the steel manufacturer who has been building these cables and turn our thoughts to the care that is given this very small diameter member that has built up such confidence in suspension bridges.

No single element, or member, in bridge building receives the close attention, tests and inspection that is given to the wire—from raw material and ingot to finished wire and cable. While, because of the enormous quantities we may think in terms of mass-production, the steel starts in the furnace in small heats, to better control its quality, and by the time the finished wire has been laid into strands, and the strands into cables, practically every foot has come under the trained eye of the mechanic, the wire-spinner and the inspector.

Taking the George Washington bridge, the biggest bridge built to date, with its over five hundred and fifty million feet of bridge wire as an example, let us consider some of the factors entering into the manufacture of the wire. Tracing the wire back to the raw material and up through the many processes of manufacture, a tabulation of *checkings, inspections, and tests*, mounts up to an astounding figure. In these computations we find years literally compressed into minutes, during the few weeks of manufacture, and results that years of usage would only partially disclose, but these checkings, inspections and tests, mean much for the ultimate safety and confidence in suspension bridges. Every shipment of raw material must be tested for carbon, manganese, silicon, phosphorus and sulphur to see that the correct percentages of these elements are in each batch before charging into the furnace, thus insuring uniformity in physical and chemical properties.

Then starting at the open hearth furnace, the metallurgist samples each of nearly 900 heats for chemical and physical requirements. By the time the

(1) Listed in rotation of erection. (2) Percentage of “bigness” comparing (E) single cables and (C) total strength of all cables on the bridge. (3) *Italic numbers indicate numerical rotation according to strength of single cable (E) and all cables (C).* (4) Top shaded line in graph indicates strength of (E) single cable, (C) the black line, all cables.

metal contained in these heats reaches the blooming mill in the form of 27,000 ingots, three additional tests have been made of each ingot. Here the ingots are multiplied into 160,000 billets and 1200 more tests are added.

In the rod-mill the method of counting changes, we measure by "miles"—the billets have changed into 160,000 coils, or 34,393 miles of rod requiring 320,000 tests for uniformity in thickness, etc. Then through the tempering and cleaning shops—and here another series of tests for physical properties, adding 25,000 to our test figures. Then, when these rods reach the wire mill and are drawn into bridge wire—through several passes or reductions, (through dies for the gradual reducing to the required wire size) the total count of coils decreased a trifle below the 160,000 (allowing for the test sampling) and the measure shows over 104,000 miles of wire, from which test samples are taken from the "front and back ends" and tested for diameter, ultimate strength per wire, or two tests for each sample, adding another 640,000 tests before they reach the galvanizing shop.

In the galvanizing shop the coils of wire are watched systematically and tested for possible imperfect galvanized surface, over-gauge, or low ultimate-strength, adding more thousands to our tests.

After galvanizing, a systematic selection of the coils is made and again sampled on front and back ends and tested for pounds per square inch at 0.7 per cent of elongation, and bending; the entire stock of the coils, both ends, are then tested for diameter; ultimate strength of wire; ultimate strength per square inch; per cent maximum elongation in ten inches—which when computed adds 1,300,000 to the test column.

In the reeling shop the thousands of miles of wire reduces to 3,873 reels as the ends are coupled together—with an especially designed coupling—and the tests for the splices required to insure at

least 95 percent of the maximum ultimate strength of the wire, adds 150,000 handlings and 15,000 additional tests, and the wire is ready for "spinning." Again the care in handling every operation of the wire manufactured is noted in the uniform tension with which the wire is wound on the reels, so as not to cause cross turns of wire, with the possibility of kinking and breaking during the spinning.

At the bridge site these 3,873 reels (142,272 feet each or total of 551,021,260 feet) are reduced to 105,896 wires in the main cables, or 26,474 wires to each of the four cables, 434 wires to a strand, and 61 strands to each of the four cables. Every wire lays parallel to its neighbor and at a predetermined sag, so that when the cable is finished they all carry an equal load—and not a foot of the wire in the spinning process is missed because it is one continuous inspection.

Then, the suspender ropes, thirty-five miles of finished rope, representing nearly ten thousand miles of wire, which is tested in the coils in a similar manner to the bridge cable wire, pile up another 113,000 for the test computation. Nearly 17,000 tests are required for over twenty-six hundred miles of cable wrapping wire.

Nearly two million and a half separate checkings, inspections and tests and the cables are ready for their load in the "big" suspension bridge. Is there any wonder then, that we continue to build "bigger" and "bigger" bridges and depend on the cable of acid-steel wire to carry the ever increasing loads?

The cable, then, is the *key* to "big-ness" and with the minute and extreme care with which it is manufactured, it seems that we can still build cables for longer bridges with still heavier traffic. A natural question, then, is—how "big" will the bridge of tomorrow be? The answer awaits the requirement—the demand of "local" traffic conditions.

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Cutting Ton-Miles

With Shortest-Line Transportation

NOT withstanding Doctor Einstein's bewildering theory of relativity, there is still a rather generally accepted belief that a straight line is the shortest distance between two points. In the airplane it is not speed alone that cuts down time between terminals, it is also its ability to follow the most direct route. The airplane is not adaptable to short-haul - heavy - tonnage material

movement problems, but there is a straight-line type of transportation that is practical and economical. A glance at the landscape, pictured on pages 110 and 111, illustrates the practicability of the tramway.

Here we have a mine located about two miles from the main line of a railway which parallels a paved highway which in turn follows the river. We shall assume, for the moment, that no roadway or railway exists on the far bank of the river, and that the daily output of the mine is 1200 tons per eight-hour day. Our problem is to convey this material from the mine to the existing arteries of transportation *and to do so by the most economical method.*

Generally speaking, we have a choice of three methods, namely:

(a) Railway

(b) Trucking over a highway, or

(c) An aerial rope transport system commonly known as a tramway.

1. First Costs

First, we analyze the problem for first costs, for invested capital. Starting at the lower left hand corner of our picture we find that a bridge is necessary for either highway or railway. Then limiting ourselves to reasonable grades for trains or



The cost per ton transported often represents the difference between profit and loss—The Aerial Rope Tramway cuts ton-miles

trucks, we begin to wind all over the map, cutting, filling and bridging as we go. After seven miles of this by the rail route, we arrive at the mine. The highway would cut this distance down to four and one-half miles. The tramway cuts the distance to two miles and eliminates all bridges and grading.

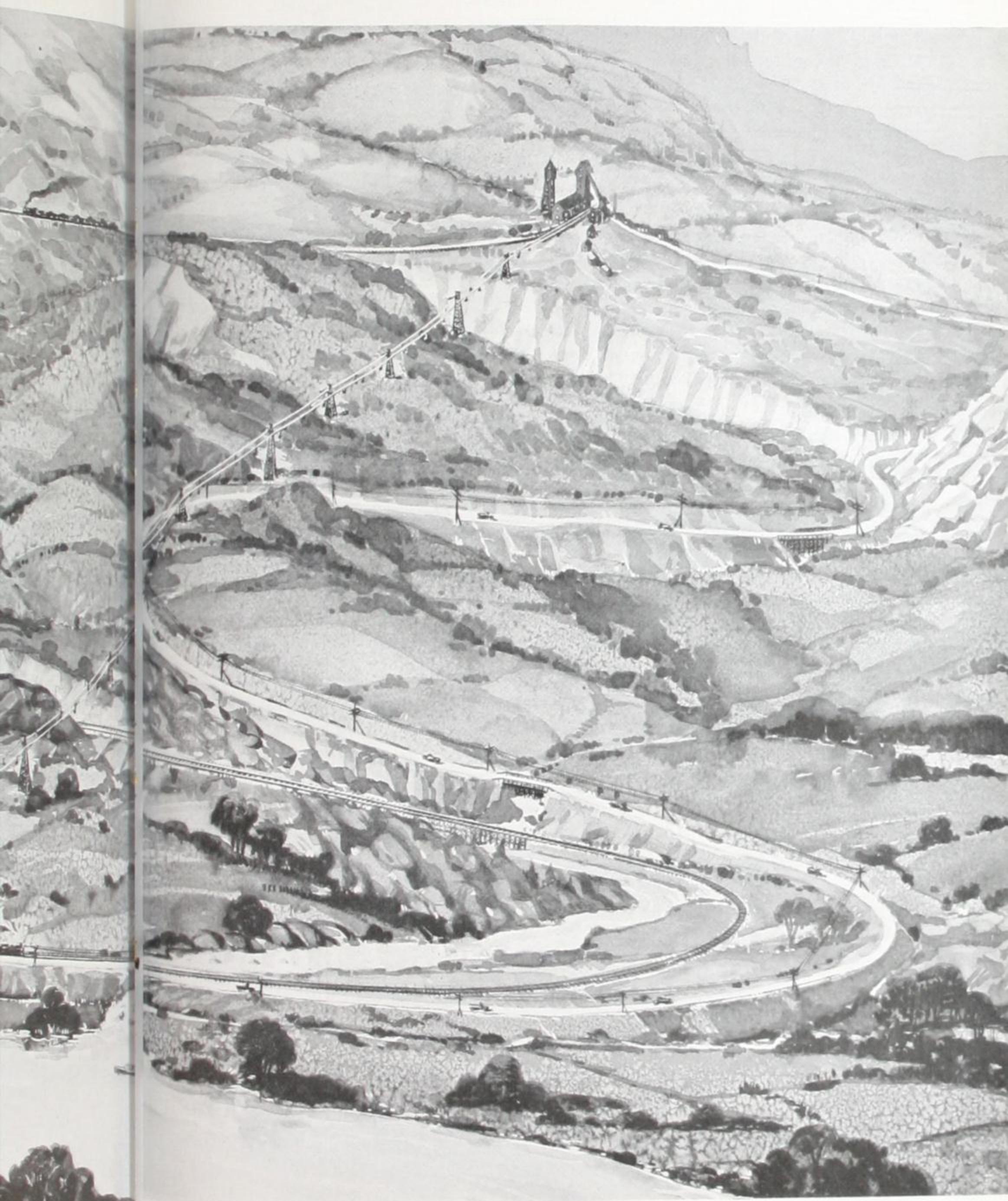
2. Operating Costs

Now, in the second place, what about operating costs? Over the railway we move 8,400 ton-miles per day. The highway with a fleet of trucks cuts this to 5,400 ton-miles per day, and the tramway figure is 2,400 ton-miles per day. And what about the return to the mine of the emptied carriers? A long uphill haul for empty trucks, and empty cars—a useless expenditure of power, for on the tramway the gravity pull of



Cutting Ton-Miles with an Aerial Rope Tramway System. The railroad moves 8,400 ton-miles per day;

The motor
tran



The motor transportation cuts this to 4,500 ton-miles per day, and the tramway further reduces it to 2,400 ton-miles per day.

The railroad

the loaded buckets is helping in the return of the empties. Ice, snow, sleet, or rain may seriously interrupt train or truck service, but these elements hold little or no terrors for the tramway.

3. Upkeep and Replacement Costs

The third consideration is upkeep and replacement costs. We won't go into actual figures, but if the tramway is properly designed, equipped with suitable ropes, and given a due amount of intelligent care, the maintenance costs will compare most favorably with that of railway or highway and truck.

With the above thoughts in mind, wouldn't you at least consider the tramway before reaching a final solution of your problem? It is a surprising fact that in very few transportation problems the tramway is investigated. This is not the fault of tramways. Engineers are thoroughly familiar with railway and highway problems, and yet because the tramway is not so well known to many, it is often thrown into the discard with no consideration whatsoever. But in doing so, opportunity after opportunity of solving the transportation problem to best advantage, is being overlooked.

There are several types of tramways with capacities ranging from three tons per hour to 150 tons per hour. By doubling up or multiplying the lines, the tonnage may be increased accordingly. The tramway, of course, has its limitations, but its merits are not given due consideration. Even in cases where highways and railways are in service, tramways have been built and used at a substantial saving because of the low operating cost.

If you have a problem involving a steady flow of material over distances from a few hundred feet up to many

miles, don't be satisfied with your solution until you are convinced that the tramway is not best suited to your needs.

The tramway is largely a cable problem, and like other problems involving the use of wire rope for the transportation and carrying of loads, their American genesis is found in the work of John A. Roebling, founder of the John A. Roebling's Sons Company.

With particular reference to aerial transportation we quote from *Outspinning the Spider*—"Persistently militant, from the day of his first achievement, in the promotion of wire rope John A. Roebling was the first engineer to introduce into America the novelty of a wire cableway, which with an ingenious carriage he employed to transport across a river the materials he needed in the construction of a bridge. This method of haulage, over streams and gorges, down from high mountains to cars or boats in the valley below, up from the deep-sunken beds of rich placers—everywhere and in all sorts of places where Nature seemed to have set up impassable defense against those who would take away her treasures—came forthwith into widespread use, and is among the handy tools of engineers throughout the world today."

The increased need, today for cutting ton-mile cost opens up many possibilities for a wider use of the aerial rope transport system, commonly known as the tramway. The data to be collected is very simple, and a tramway engineer needs only to know the capacity required; the nature of the materials to be transported, and the power available together with a simple profile of the ground between terminals, to enable him to give suggestions that may lead to substantial savings in production costs.

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Selecting The Right Type

Aerial Wire Rope Conveyor

Saving time and expense in transportation of materials. Six types of aerial conveyors that cut ton-mile costs. A type for the economic handling of materials over a few hundred feet to several miles.

THERE is such a wide variation in the requirements of various undertakings such as mines, quarries, industrial plants, building, bridge and conduit construction, shipping, etc., that several distinct types of tramways and cableways have been evolved. The principal types are:

1. The Single Rope Fixed-Clip Tramway which runs at low speeds with small loads.

2. The Monocable or Single Rope Saddle-Clip Tramway which runs at speeds up to 500 feet per minute with capacities up to 250 tons per hour on single lines.

3. The Bicable or Double Rope Tramway which has the same speeds as the Monocable.

4. The Jigback or Two-Bucket Reversing Tramway.

5. The To-and-Fro or Single-Bucket Reversing Tramway.

6. The Hoisting and Transporting Cableway, having a reversing carriage provided with hoisting and lowering facilities at the carriage.

The prospective tramway user should not decide upon any one type until he has given careful consideration to the



Fig. 1—Typical Monocable Tramway—View on Line.

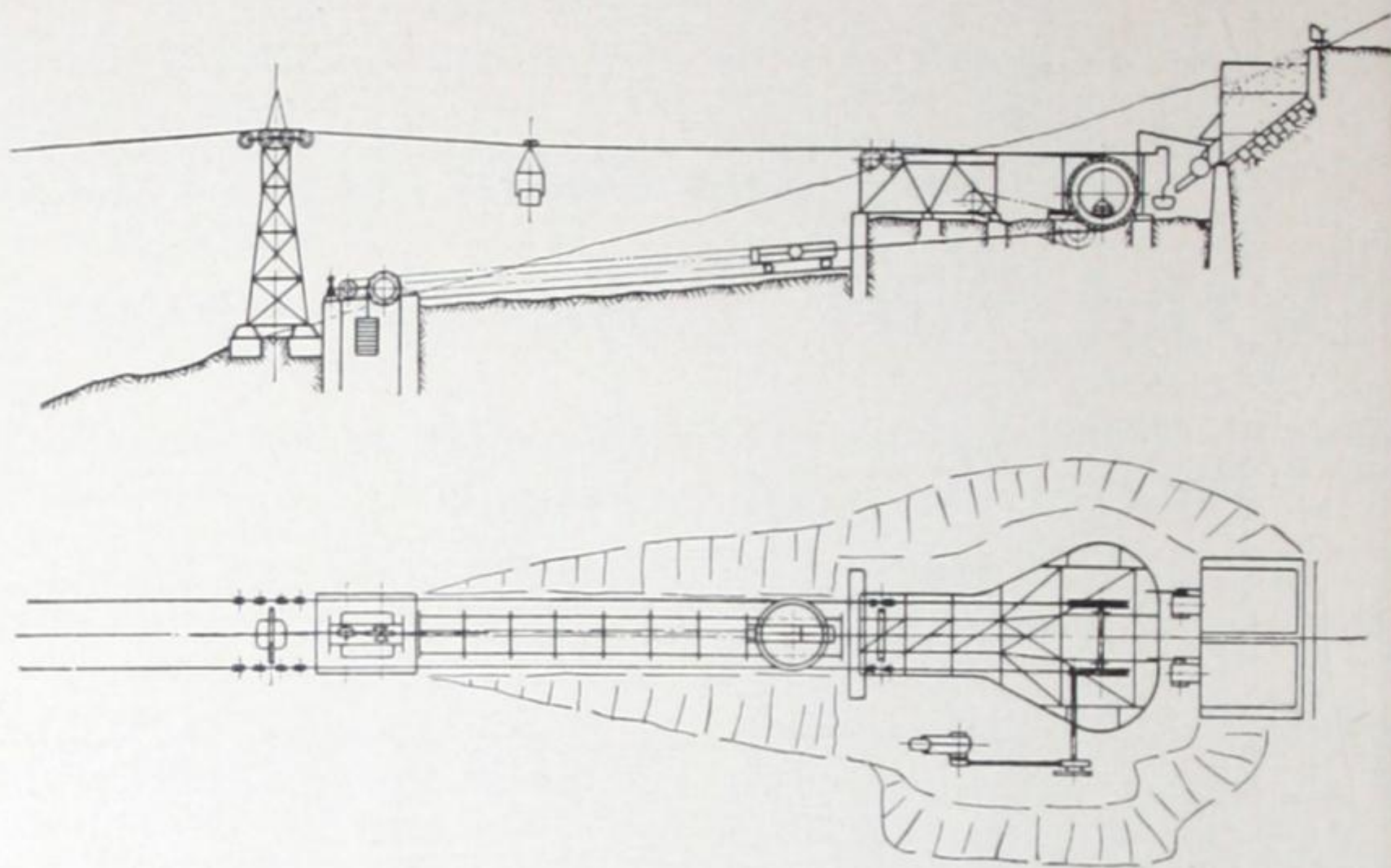


Fig. 2—Typical Terminal of Monocable Tramway

merits and limitations of each as affecting his particular transportation problem.

1. The Single Rope Fixed-Clip Tramway consists of an endless rope having buckets or carriers fixed to the rope at intervals. This rope passes around a horizontal sheave at each terminal and is provided with driving gear and a constant tension device. This type of tramway is used for the trans-

port of bananas from various points in the plantation to the railroad or steamer. It may be loaded at any point on the line as the speeds are low and there is no necessity to stop the carriers in order to load them. This type of tramway is also used in plantations for transporting bags of coffee, cocoa, cotton, fruits, rubber, sugar cane, corn, etc. Such installations can be fabricated, shipped and erected for as little as \$11,000 per mile



Fig. 3—Typical Bicable Self-Dumping Terminal

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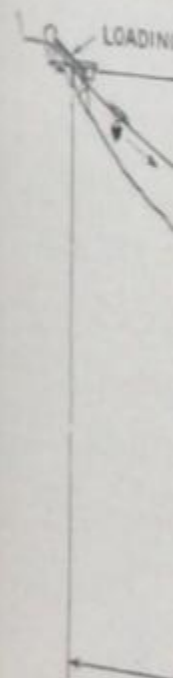


Fig. 5—A

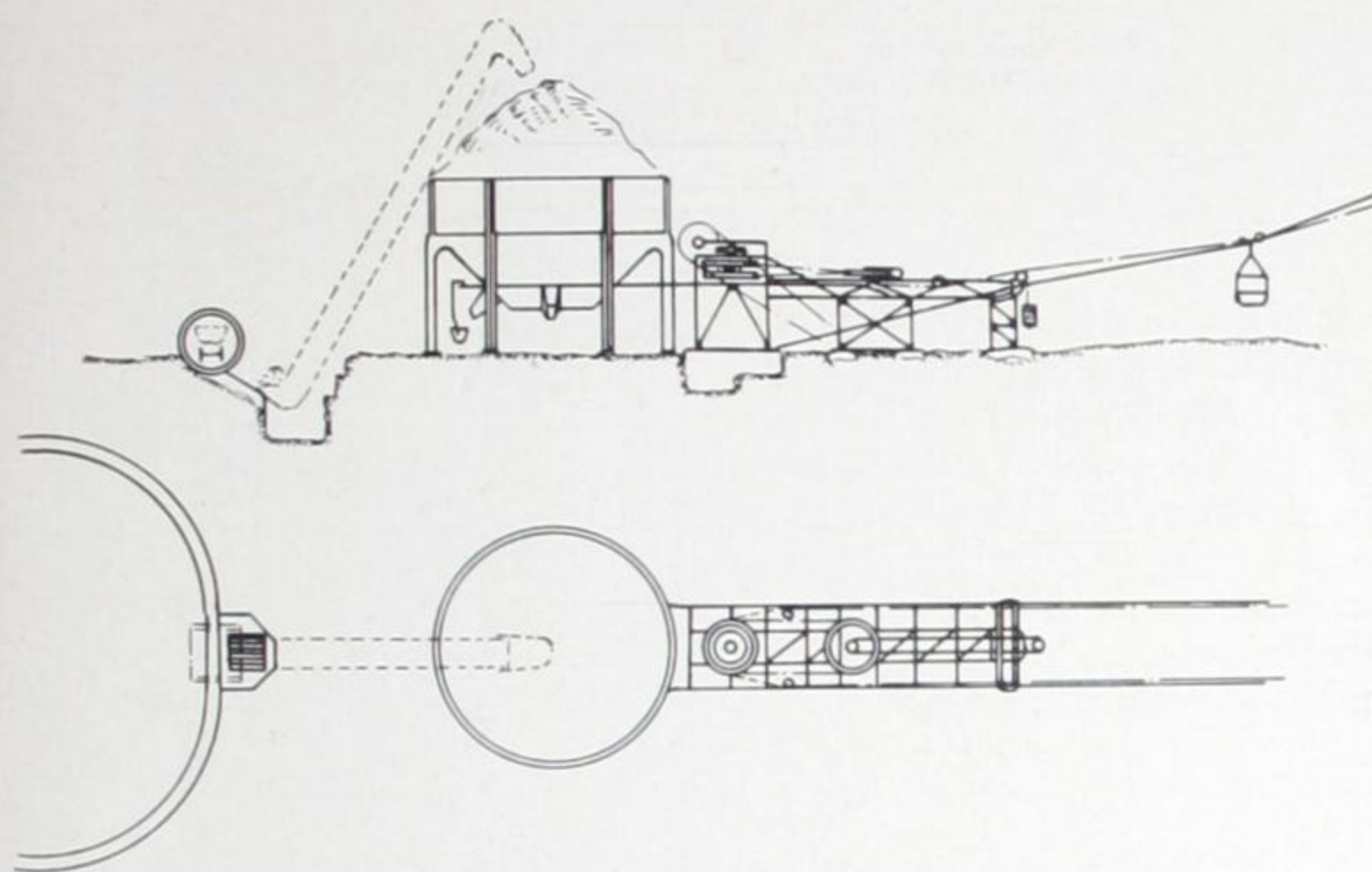


Fig. 4—Typical Terminal of Bicable Tramway

In the case of a banana line the bunches can be transported at an operating and maintenance cost of one-tenth of a cent per mile per bunch.

2. The Monocable Tramway, throughout the world, is generally the most widely used form of tramway today. It will operate on grades up to 1 in 2 or 50% and single line capacities up to 250 tons per hour in each direction. It can be operated in single sections, depending on capacity, up to 16 miles in length without intermediate stations or tension points. It can be

operated in multiple sections without transshipment up to any desired length.

There is a notable case in Colombia, South America, where the line is 47 miles in length, and carries general merchandise of all kinds, including regular and parcel mail, gasoline, machinery, dry goods, foodstuffs, coffee, etc.

Other monocable lines under construction and partly operating will have a finished length up to 170 miles, passing over some of the densest jungles and swamps on the Pacific Coast and over some of the greatest ranges and

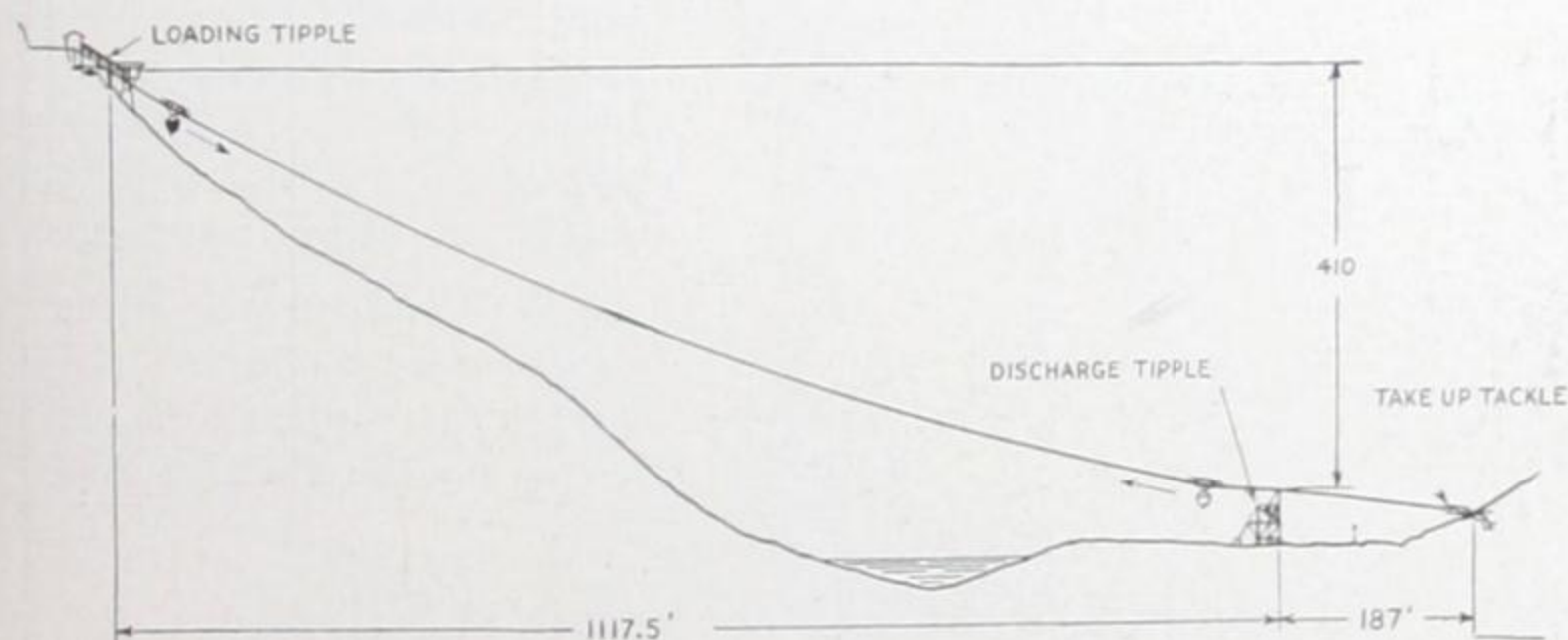
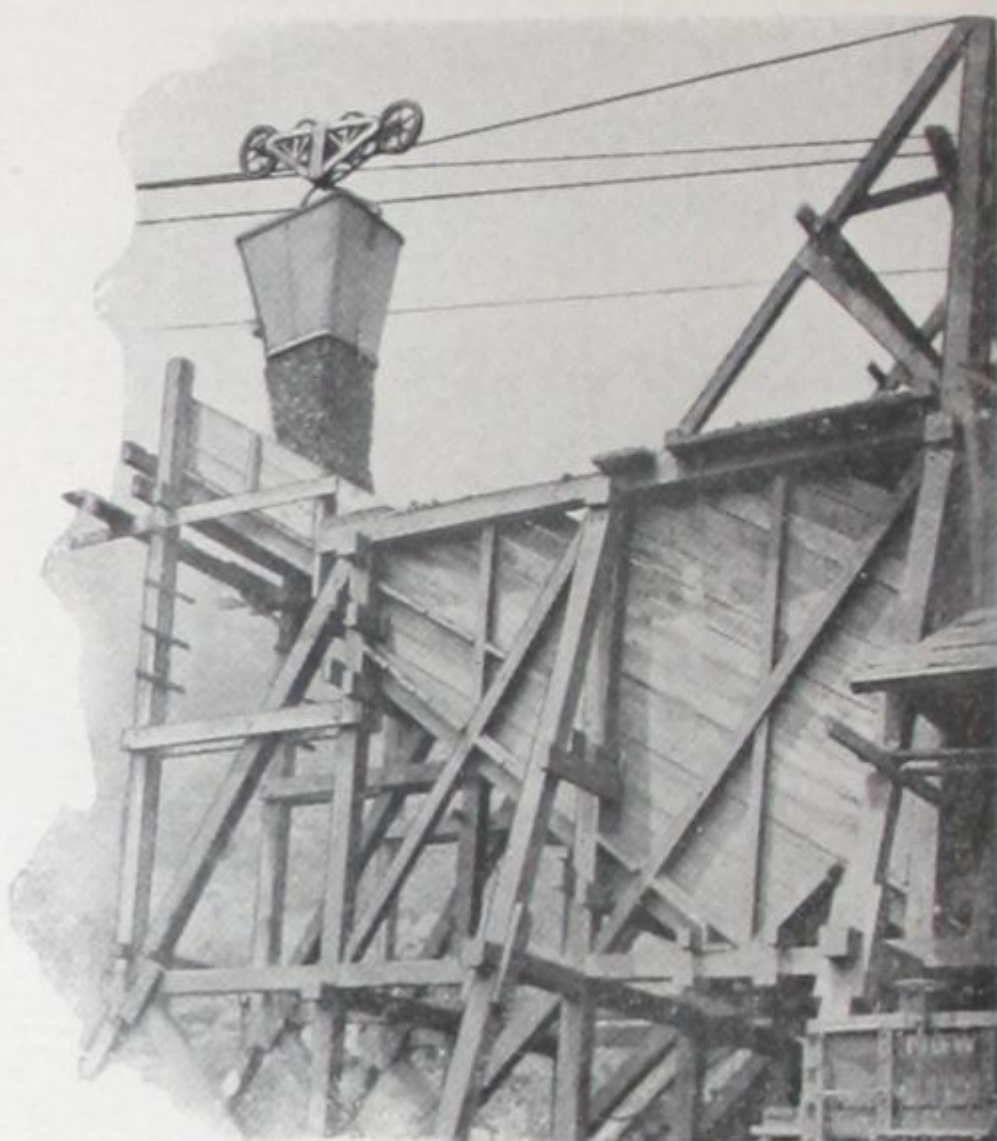
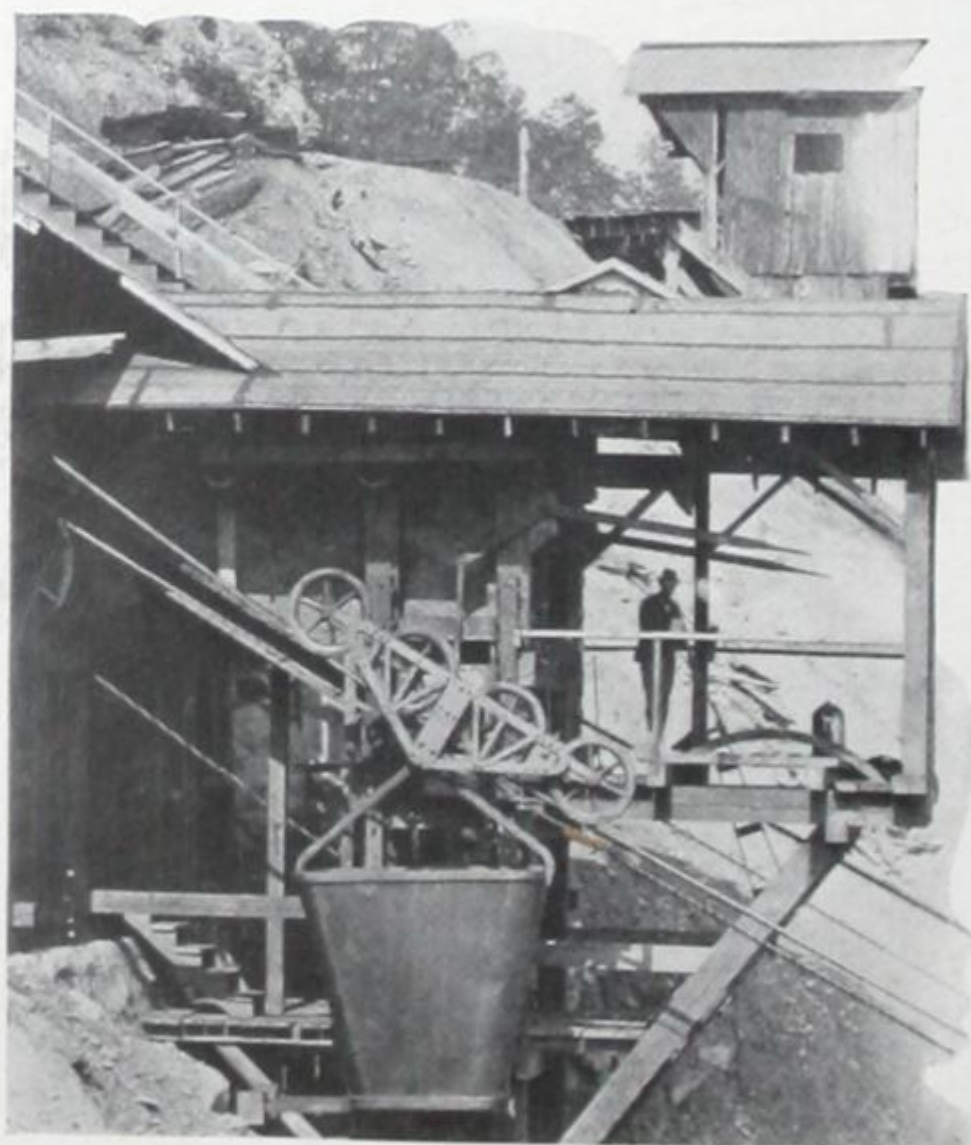


Fig. 5—A Jigback Tramway. (A To-and-Fro Tramway is similar, except that there is one Track and one Bucket.)

Fig. 6—Loading Terminal
of Jigback Tramway

canyons of the Andes. These monocable installations can be furnished and erected for as little as \$15,000 per mile, for light capacity and long lengths. Essentially the system consists of a moving endless rope which supports and hauls the loads at the same time. At the terminal and angle stations the loads automatically leave the moving rope and pass on to an overhead rail. At this transfer point the rope and rail are parallel and close to one another. No detaching nor attaching device is necessary, nor depressions in the rail. The Monocable has been generally found to be most economical in cost of installation and operation, produces lower ton-mile costs and safer operation, less delays in running repairs and a less highly skilled personnel. Moreover, the main rope, being in constant passage through the



terminal stations is kept under close and rigid inspection at all times. Lubrication of the rope is automatic and simple. The cars are very light and simple in construction having less tare (or non-paying) weight. These monocables are so safe and simple in operation that they are used for passenger service.

3. The Bicable or Double-Rope Tramway consists of a standing track cable and a moving endless hauling or traction rope. In certain special cases, such as excessively steep grades or excessively heavy unit loads the Bicable may be desirable, but normally the great majority of tramway requirements are best served by the Monocable.

In the Bicable station there is a *detacher* and an *attacher* which devices serve to open and close the car-grip on the traction rope. A

Fig. 7—Discharge Terminal
of Jigback Tramway.

a rule, owing to the track cable of the track cable and counterweight 7000 feet.

4. The Jigback Reversing Tramway hillside operation the loads go on of sufficient gravity. In required and control purpose with unit trip, and cables, a track practically, fixed to the the loaded but the empty on

5. The To Single-Buckle Tramway co single-track single traction ated on a hoist drum. is suitable for up to 3 ton mittent work hillside.

6. The H Transporting is a to-and carriage system in addition rope for pick depositing loads. To slack in the h a system of spaced carriage ployed, hanging track cable, by various-

Fig. 8—A
Transporti

a rule, owing to the friction of the stiff track cable over the tower saddles, etc., the track cable is arranged in sections and counterweighted at every 6000 to 7000 feet.

4. The Jigback is a Two-Bucket Reversing Tramway usually applied to hillside operation for mine workings. If the loads go down hill the line will, if of sufficient grade, operate itself by gravity. In this case no power is required and a brake is employed for control purposes. These jigbacks operate with unit loads up to 10 tons per trip, and consist of a pair of track cables, a traction rope and a tail rope or, practically, an endless traction rope fixed to the two buckets so that the the loaded bucket going down hill pulls the empty one up hill.

5. The To-and-Fro or Single-Bucket Reversing Tramway consists of a single-track rope and a single traction rope operated on a winding or hoist drum. This system is suitable for light loads up to 3 tons for intermittent working on a hillside.

6. The Hoisting and Transporting Cableway is a to-and-fro single carriage system but has in addition a hoisting rope for picking-up and depositing transported loads. To carry the slack in the hoisting rope a system of equally spaced carriers is employed, hanging on the track cable, and spaced by various - sized but-

tons on a taut button rope across the span. These cableways are generally used for the construction of dams, bridges, dock and harbour works and big buildings; coaling of ships; loading and discharge of general cargo from ships; pouring of concrete for the foundations of large buildings; placing of steelwork members, machinery and flooring on buildings, warehouses, docks, piers and bridges. The cableway has been used successfully for many years on some of the foregoing classes of work, but the merits of this highly useful piece of handling equipment have not yet been fully realized.

This type is furnished with (a) both towers fixed; (b) one fixed and one travelling radially; (c) both travelling.



Fig. 8—A Hoisting and Transporting Cableway.

Cableways have been installed up to 3000 foot span. The unit loads to 50 tons per trip. Designs have been completed for a cableway to transport a 150-ton unit load.

Six types of tramways—which in themselves, or adaptations of the principles involved, constitute economic transportation for many industrial and construction projects. A careful study

of this group will show where aerial rope transportation can be installed and maintained at a considerable saving over rail or high-way methods which require building of road-beds, bridges, etc., for the moving of materials over distances of a few hundred feet to several miles, from the source of raw material or plantation to the processing plant or shipping point.



Erected



SKY-RIDE

Erected at The Century of Progress Exposition, Chicago, Ill., 1933.

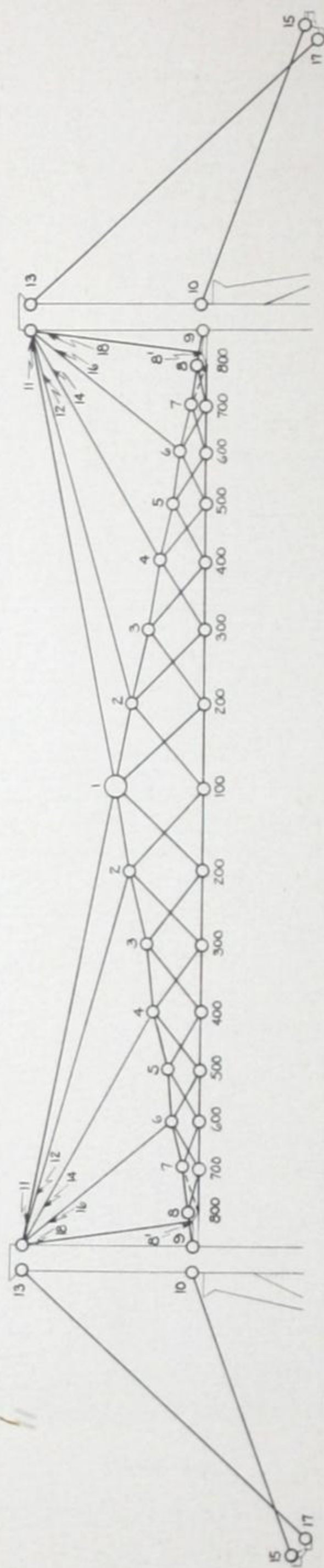


Fig. 1—Diagram of Towers, Cables and Anchorages of the Sky-Ride.

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The Sky-Ride

Some Design Features

THE Sky-Ride, which transported approximately one and a half million passengers during the Exposition "A Century of Progress", held in Chicago, Illinois, in 1933, was a unique structure from many angles. It may be termed a cross between a suspension bridge and a heavy-duty tramway, for it partakes of the characteristics of both. And yet, like all hybrids, it has certain distinguishing features which are peculiar unto itself.

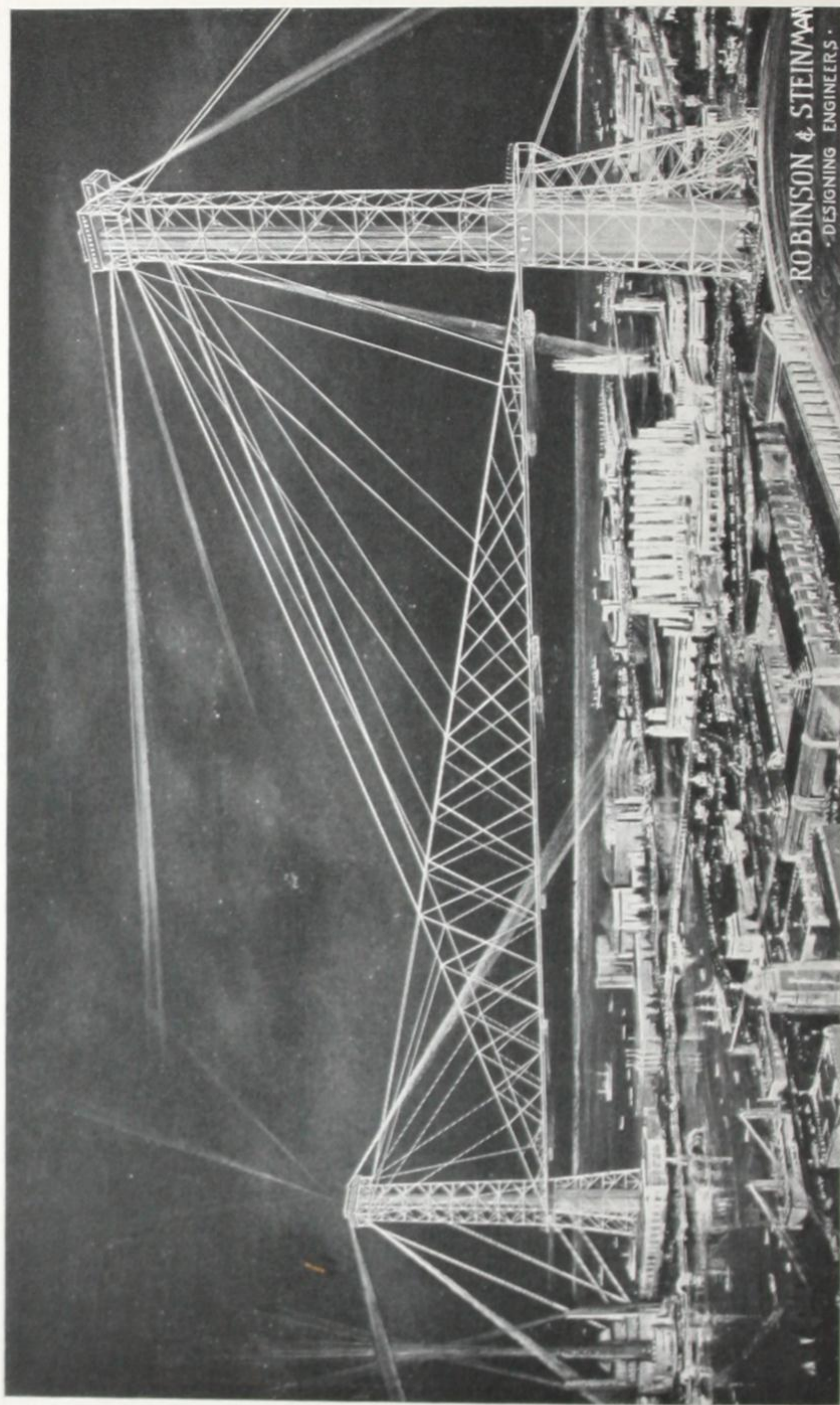
Figure 1 shows the general arrangement of towers, anchorages, cables of the suspension system and track cables of the Sky-Ride proper. The sole function of the suspension system is to support the track cables on which travel the so called "rocket cars." For reasons of comfort to passengers, to reduce power consumption to a minimum, and, as a requirement of safety, to eliminate excessive grades, it is evident that the path of travel of the cars must be as nearly in a horizontal plane as is practicable.

Of course, the introduction of a stiffening truss, such as is provided on the conventional suspension bridge, would have solved this problem nicely, but the addition of such a truss would have increased the cost of the structure manifold. To meet these requirements, and to do so with some measure of

economy, an entirely new suspension system was devised.

The track cables may be considered as the lower chord of a triangular truss (9 East-1-9 West), all members of which are in tension. The top chords are the two cables (1-9) and the diagonals are the track cable suspenders (1-200), (2-100), etc. The apex of the triangle is supported by the main suspension groups (1-11) and the cables forming the two legs are supported at intervals by the stays (2-12), (4-14), etc. The behavior of the triangle under the moving concentrated loads is substantially the same as a truss supported at the two ends (9E and 9W)—and entirely different behavior from that which is characteristic of the stiffened suspension bridge.

No cables or groups of cables are fixed or dead ended to the towers. All vertical reactions from the suspended system are transmitted to the towers through links and pins so that practically no unbalanced horizontal force has to be taken by the towers, other than the wind load on the towers themselves and suspension system. The resultant horizontal component from the main suspension group (1-11) and from the diagonal stays, is carried into the main backstay group (13-17) which is in turn secured to a fixed gravity type anchorage (17).



SKY-RIDE
Enlarged View showing Details of Construction.

Span, 1850 feet. Tower, 600 feet.

It will be group (11E- top of one t ft. level on t tically a stra it joins with the resultant both groups, supported ten backstay gro terminates, n anchorage as in a rocking g in reality, a co less of suspens or temperatur the lower h remains const

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It will be noted that the cable group (11E-1-9W) carries from the top of one tower to about the 200 ft. level on the other tower, in practically a straight line. Here at point (9) it joins with the track cable group and the resultant horizontal component of both groups, is carried through a link supported tension member to the lower backstay group (10-15). This group terminates, not in a fixed gravity anchorage as did the upper group, but in a rocking gravity anchorage which is, in reality, a counterweight. So, regardless of suspended loads, wind conditions or temperature changes, the tension in the lower backstay group (10-15) remains constant.

The horizontal component, therefore, at point (9) is, within very narrow limits, a known and fixed quantity. While it is difficult to "chase the stresses around" through all the cables, it can be readily appreciated that with constant given horizontal forces applied at points (9E) and (9W), the determination of stresses in all members of the systems, under the numerous different loading and temperature conditions, is greatly simplified.

With this brief description of the suspended system in mind, it is proposed to digress for a moment and see why this particular design was adopted and how the stresses in and the sizes of the various members, were determined.

The choice of the suspension system and its ramifications necessarily depended upon past experience coupled with present requirements. A lot of time can be saved if a solid knowledge of the fundamentals is at hand.

Before arriving at the final design, a series of suspension systems was evolved. Each scheme had its merits, but study

eliminated all but four. Approximate, but still extensive calculations were made and by this means the field narrowed down to three possibilities. To facilitate a full comprehension of the problem, approximately true-to-scale models were built. With this material available, observation and studies eliminated all but one system, and this one, in principle and appearance, is that of the present Sky-Ride.

The fact that type and general requirements were now known, made possible the preliminary design of certain governing items. For instance, it became feasible to incorporate the counterweight, because the models showed the necessity for an approach to a constant tension system. A system was required that would induce little tower motion (it should be remembered that there are two heavy duty high speed passenger elevators serving the top of each tower) and one that would minimize temperature effects. It was also determined that four separate suspension systems, arranged in pairs, each pair supporting four track cables, would be desirable.

Accordingly, a new model embodying these principles was built. The new model was nearer true to scale than had been possible before. Sizes of strand and permissible weights of cars having been determined, readings of stresses and elevations were obtained from the model. These elevations were taken after the model members had been so adjusted that when a load, equivalent to a loaded car, passed through a suspension point, that point would deflect into the same horizontal plane as that which all other points of support on the track cable would seek, under the equivalent concentrated load. The cable stresses and elevations of all intersection



SKY-RIDE
Enlarged View showing Details of Construction. Span, 1850 feet. Tower, 600 feet.

ROBINSON & STEINMAN
DESIGNING ENGINEERS

points were thus approximated and the resulting influence lines drawn.

That the suspension system is indeterminate can readily be seen from the sketch. There is apparently no direct and straightforward solution for stress determination. Before going into the method of arriving at these final figures, it may be well to insert a few remarks covering computations of cable curves in general.

In the first place, a wire cable is an elastic member and deflections are a function of the modulus of elasticity, which in a prestressed bridge strand is approximately 24,000,000 pounds per square inch. The first step in the solution of a cable problem is the fixing of a known ground or unstressed length. This ground length is determined by removing the stretch from the length of member under the loading condition assumed.

Secondly, the solution of any suspension system may be approached by either the catenary or parabolic theory. A solution of the Sky-Ride system may even be roughly approximated by a straight line treatment. That a catenary solution is the more accurate is unquestionable.

The first problem is to determine the unstressed length of each member of the structure, and because of the complexity of the Sky-Ride suspension system, the most accurate method of computation is mandatory. A basic condition of cars at point (100) and 450 feet east and west of this point was assumed. The weights of fittings and applied loadings were determined. With these weights, assumed sizes and elevations taken from the model, computation was started.

The stress in (1-11) as recorded by extensometer on the model, was

assumed to be correct, as was the stress in the track ropes. Then, by solving the pairs of suspenders (200-1), and (200-3), etc. as intersecting catenaries, their length, stretch and vertical reaction, at points on the lower suspension cable were determined.

The next step was to establish equilibrium at the point of intersection of several catenaries. This implies necessarily that the sum of all horizontal and vertical forces be zero respectively. At point (1), for example, the stress in cable (1-11) was known (from model), and the reaction of (200-1) was calculated. It only remained, then, to fix the stress in, and to determine the length of cable (1-2).

The equilibrium of the remaining points was established in the same manner, 1-2-3-4-5, etc. having been computed in that order until point (9) was reached, at which point the unbalanced horizontal component was equal and opposite to the known horizontal component from the counter-weighted backstay group.

The completion of this basic set of calculations affords the means of further computation. The unstressed length of each member having been determined, the problem of live load deflection was attacked by a series of successive approximations, again treating all members as catenaries. When the deflection assumed, resulted in a stressed length whose ground length checked against that assumed, the deflection was regarded as correct.

The whole problem of successive approximation and intersecting catenaries may seem involved and complicated. Actually, the work was tedious but not materially difficult.

There are unquestionably other methods of attack, such as a truss

Track Dead
Live.
Temp

(1-11) Dead
Live.
Temp

(2-12) Dead
Live.

(1-2) Dead
Live.
Temp

(2-3) Dead
Live.
Temp

(13-17) Dead
Live.
Temp

*Normal Operation**Emergency Operation*

Track	Dead.....	120,400—	86.0%	Dead.....	120,400—	81.2%
	Live.....	11,700—	8.3%	Live.....	19,600—	13.2%
	Temperature.....	8,300—	5.7%	Temperature.....	8,300—	5.6%
		140,400—	100 %		148,300—	100 %
(1-11)	Dead.....	124,200—	86.8%	Dead.....	124,200—	80.9%
	Live.....	10,500—	7.3%	Live.....	21,000—	13.6%
	Temperature.....	8,400—	5.9%	Temperature.....	8,400—	5.5%
		143,100—	100 %		153,600—	100 %
(2-12)	Dead.....	21,100—	64.7%	Dead.....	21,100—	47.8%
	Live.....	11,500—	35.3%	Live.....	23,000—	52.2%
		32,600—	100 %		44,100—	100 %
(1-2)	Dead.....	92,600—	84.0%	Dead.....	92,600—	77.6%
	Live.....	9,200—	8.4%	Live.....	18,400—	15.4%
	Temperature.....	8,400—	7.6%	Temperature.....	8,400—	7.0%
		110,200—	100 %		119,400—	100 %
(2-3)	Dead.....	73,800—	84.7%	Dead.....	73,800—	80.1%
	Live.....	5,000—	5.7%	Live.....	10,000—	10.8%
	Temperature.....	8,400—	9.6%	Temperature.....	8,400—	9.1%
		87,200—	100 %		92,200—	100 %
(13-17)	Dead.....	235,000—	86.0%	Dead.....	235,000—	82.3%
	Live.....	25,800—	9.5%	Live.....	38,400—	13.4%
	Temperature.....	12,200—	4.5%	Temperature.....	12,200—	4.3%
		273,000—	100 %		285,600—	100 %

analogy with its influence lines, that are less boresome; but the fact remains that each and every cable does hang in a catenary, and therefore the solution based on the theory of the catenary is, in the final analysis, the only exact treatment.

Set forth in the table on page 125 are the dead, live and temperature stresses covering extreme ranges, and total stresses in some of the principal cables and groups for both normal and emergency operating conditions.

Normal operating conditions consist of fully loaded cars weighing 16,500 lbs. each, spaced 700 ft. apart, and running at a speed of 520 ft. per minute. Emergency operating conditions consist of two cars together with a third car 700 ft. distant. The temperature stresses are for plus or minus 60° Fahrenheit.

All bridge strands in the system are designed with a factor of safety of three, based on emergency loadings coupled with the worst temperature conditions. This is the generally accepted practice in suspension bridge design. The track cables have a safety factor of four, under like conditions.

Practically all cables in the entire system are made discontinuous at intersection points or terminals. This is done to simplify the design of fittings and also to make for ease of erection. As a result, however, we find 328 separate cables in the system, 38 of which are different lengths. The erection and adjustment of such a system would hardly be practicable were not all cables prestressed and then measured to exact length while under their calculated working tensions.

Prestressing, a distinctive Roebbling innovation, measuring under working tension and cutting to exact length

has been developed to such a stage by this Company in connection with suspension bridge work, that the chief reliance of a properly adjusted system is placed on exact lengths and elastic behavior. To count upon field adjustment in this case would be like trying to tune a piano wherein the ends of all wires were attached to a common flexible member. Unless all were adjusted simultaneously, the task would prove endless.

As pointed out previously, the track proper in the main span is made up of four 1½" Locked Smooth Coil Cables, all in the same horizontal plane. Each of the ten cars is suspended from four separate two-wheel trucks, making a total of eight wheels per car, the car hanging from one central trunnion point, which is located directly above the center of gravity of the loaded car.

For various reasons the single point suspension for passenger cars on aerial tramways is essential, although it is true that this method of suspension is a source of wonder to the uninitiated observer. The sight of a relatively long car, hung from a central point like a pendulum, at once arouses visions of pitching or longitudinal swaying. However, the many years of research, experiment and practical working that lie behind the modern, highly developed aerial passenger tramway, have shown the superiority, in point of safety and ease of handling, of the single point suspension.

Many attempts have been made in the past to suspend such passenger cars from two or more points on the cable, but without success. One has only to look at any, or all of the aerial rope tramway passenger lines now in operation in various parts of the world, to see that

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the consensus of opinion, among the manufacturers, designers and operators of these passenger carrying aerial rope tramways, is in favor of the single point suspension.

The reasons are not far to seek. Seeing that the track cable must have a certain sag, the result of a two point suspension would be an undesirable tilting up and down of the car when approaching and leaving track cable supports, such as towers, stations, etc. The advantage of the single point suspension is that, as a pendulum, the weight of the car maintains it on an even keel, whatever the grade the car truck happens to be ascending or descending.

Another point is the effect of a head-on or a following wind. In the case of a two point suspension, the tendency of the wind would be to make use of either the forward or rear truck as a fulcrum, thus lifting the other truck off the track with the imminent danger of derailment.

Two point suspensions also cause considerable trouble in passing supports and in traveling around the curved rails in the station and at switch points.

Experience has shown a high percentage of derailments with two point suspension freight cars, partly due to the tendency of two point suspensions to bind on the curves and thus ride up and off the rail.

Proper attention in the design to questions of speed of acceleration and braking, practically eliminates the pitching of cars at starting and stopping. It is at starting and stopping that such motions are most likely to occur. When actually travelling, pitching, or longitudinal swing does not develop to any appreciable extent. Wind, as a rule, only deflects slightly the vertical axis of the car and maintains this deflection with-

out setting up any serious swinging motion.

Although by limitations of deflection of the track cables in this installation, with the resultant reduction of the grade, we have minimized some of the objections to two point suspension, yet other restrictions make it necessary to adhere to the single point suspension.

By computation and test the cars in the Sky-Ride installation have been provided with an arrangement of oscillation control that fixes the movement in such a manner that the cars will ride practically without swing and at the same time there will be no couple tending to lift any of the wheels off the track cables.

The cars while in the main span are hauled by means of endless traction ropes, which are in turn driven by winding machines mounted on hanging girders bracketed from the towers. They grip and ungrip automatically to and from the traction rope when leaving and entering the tower trusses respectively. There are four of these trusses, each about 70 ft. long and extending from the two outside faces of each tower toward mid-span.

While travelling along these trusses, through the unloading station, around the back of the tower, through the loading station and out again to the track cables, the cars are suspended from stiff rails and each travels under its own power which is derived from two motors mounted on the inboard trucks.

The interlocking safety appliances with which the cars, stations, tracks, etc. are equipped, are too numerous and involved to admit of description here. It has been our purpose here simply to point out some few of the many prob-

lems that John A. Roebling's Sons Company, as one of the several participating contractors, was called upon to solve, and to give some idea of the steps taken and the ground covered in reaching what proved to be satisfactory solutions of those problems.

The Sky-Ride at Chicago was erected

as a mechanical attraction for the World's Fair and we make no sweeping claims as to its adaptability as a commercial transport system. However, it requires no great stretch of the imagination in these times of increasing traffic congestion, to visualize the application of this principle to the solution of some of our transportation problems.

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Suspension Bridges

THE suspension bridge embraces many features of design which make it the ideal type of bridge for diverse river, ravine, street or railway crossings.

Because of the growing popular demand that beauty go hand in hand with utility and economy, there is a marked trend toward the aesthetic in

erection. The highly economical long spans reduce to a minimum, or in many instances eliminate entirely, costly submarine foundations and pier work.

A sample from every coil of wire used in the cables is tested to destruction before it is put into service. The long life of the Brooklyn, Williamsburg, and many other bridges, notwithstanding



Brooklyn Bridge

present-day bridge design. The suspension bridge is pre-eminently a structure of beauty; its natural graceful lines blending with any surroundings, make it stand out as a monument of progress.

Beauty is not the only virtue in which the suspension bridge excels. It is a simple, safe and durable structure. Its erection involves no hazardous cantilevering nor false-work. Traffic need not be tied up, nor diverted during

increased traffic conditions which were not dreamed of at the time they were built, is ample testimony of the dependability and durability of Roebling Bridge Cables.

In the design of a suspension bridge, the engineer is not placed under the handicap of working with unknown conditions, and in using Roebling Wire Cables he is dealing with materials which have, without question, successfully passed the severe tests of time and extreme service.

All our Bridge Wire and Bridge Cables are manufactured in our own plant, of the best and most reliable materials. Only cold-drawn wires made from acid open-hearth steel are used in "Cables by Roebling".

The John A. Roebling's Sons Company maintains a Department of Bridge Engineering, which will gladly co-operate with designers, furnish designs, specifications and estimates on all types of suspension bridges.

and for connecting the upper stories of detached buildings. For inaccessible canyon, gorge and ravine crossings where it is impracticable to transport heavy materials by rail or truck, the relatively light members of the suspension bridges can be readily transported by means of pack trains or man power.

We furnish detailed erection plans and instructions with material, ready for



Penn Public Service Corporation Bridge, Rockwood, Pa.

Footbridges

The Suspension Footbridge is a light, graceful, economical, and easily erected structure. The prospective builder of any bridge for pedestrian traffic, should investigate the advantages of the suspension type before making a final decision.

This type of bridge has been erected with gratifying results in parks, school grounds, on golf courses, for river crossings at factories and mines, railroad crossings at terminals and elsewhere,

erection in the field, thereby simplifying field supervision and reducing field labor to a minimum.

We are in a position to supply, on short notice, the following materials for small bridges:

Cables	Anchorage Steel
Cable Bands	Saddles
Cable Clamps	Suspender Ropes
Bridge Sockets	Suspender Rods
	Turnbuckles

Also Tower and Floor Steel Work.

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Corbett and Stuart Bridge, Corbett, N. Y.

Light Highway Bridges

Many estates, farms, stores, factories and communities, are just "across the river" from the paved highway. The light suspension bridge is a most satisfactory means of placing them on, or within easy reaching distance of the main road. These bridges add to the scenic beauty of any locality. They are quickly erected, the comparatively light weight of material used, making heavy, expensive erection equipment unnecessary.

Across streams or rivers subject to flood conditions, they are especially desirable, as the towers are set well into the shore thereby allowing the unobstructed flow of water and debris during floods.

Roebling Bridge Cables are today supporting many light highway bridges in different parts of the world. The span may be upward to 600 ft. in length, and one or more lanes for traffic can be provided.

The Bridge illustrated above on this page connects a small industrial community with a state highway. There are many other localities where just

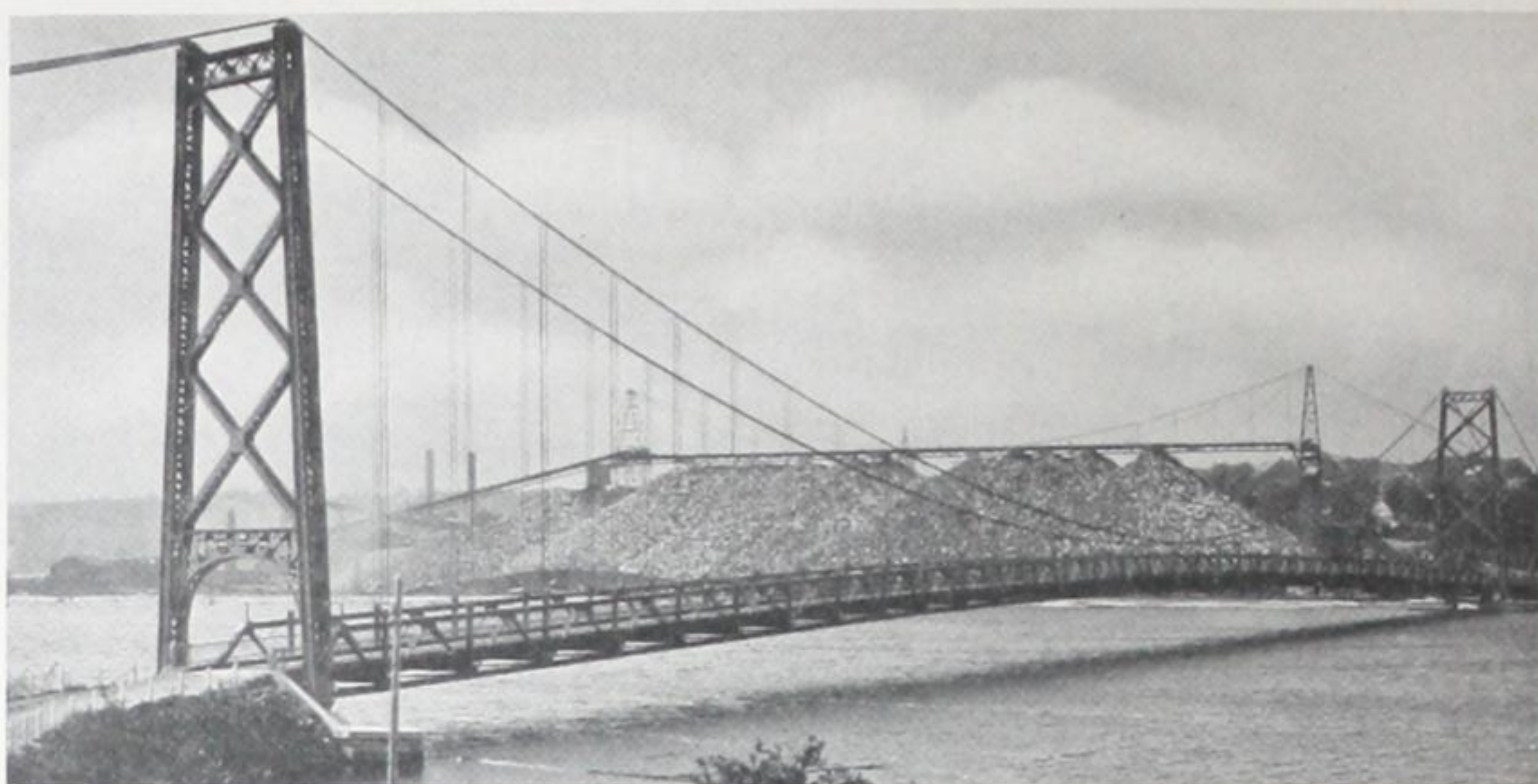
such a bridge is needed. Let us help solve your problem.

Intermediate Span Highway Bridges

We have developed a new type of pre-stressed bridge strand cable for spans requiring individual cables of not more than 215 square inches of cross-sectional area, the use of which materially reduces the cost of such structures.



St. Johns Bridge, Portland, Oregon, during erection. Each of the two main cables for this beautiful new bridge is composed of 91—1½ diameter Roebling Galvanized Bridge Strands.



Grand' Mere Strand Suspension Bridge, Quebec, Canada. Pulp Conveyor Bridge in background

The main cables are composed of a number of high strength galvanized bridge strands with a minimum guaranteed modulus of elasticity of 24,000,000 pounds per square inch. The strands are laid parallel in the main cable. The structural stretch of bridge strands which has heretofore limited their use on intermediate span Highway suspension bridges, has been eliminated by our recently developed pre-stressing process. Our new compact type of anchorage, used in connection with the bridge strand cable, also effects a saving in time and cost of erection.

The 949 feet span highway bridge at Grand' Mere Quebec, the new 1207 feet St. Johns highway span at Portland, Oregon, and the 1060 feet span highway bridge erected across the Ohio River at

Maysville, Kentucky, are notable examples of bridges using Roebling Multiple-Strand Main Cables.

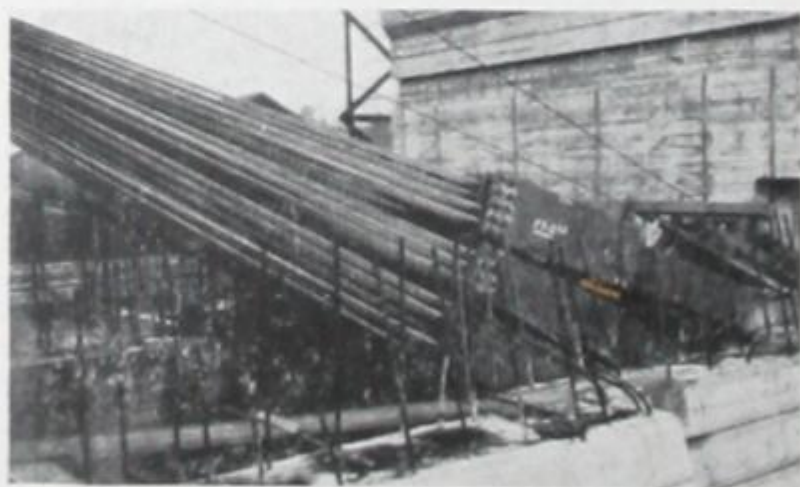
Long Span Highway Bridges

The Superiority of Parallel Wire Main Cable Suspension Bridges for spans is definitely established. With four exceptions this Company has furnished the cables for every large suspension structure of this type in the United States. "Cables by Roebling" is more than a phrase, it is a guarantee of reliability and service. Following is a partial list of America's great suspension bridges built with Roebling Cables.

Bridge	Date	Span
Brooklyn Bridge	1883	1,595 ft.
Williamsburg Bridge	1903	1,600 ft.
Manhattan Bridge	1909	1,470 ft.
Bear Mountain Bridge	1924	1,632 ft.
George Washington Bridge	1931	3,500 ft.

Other Suspension Structures

The suspension bridge principle is readily adaptable to other commercial and construction requirements, as for example: Pulp Wood Conveyors, Belt Conveyors; Pipe Line Crossings; Suspended Roofs of hangars and similar large buildings where unobstructed floor space is at a premium.



Compact type anchorage for bridge strand cables.

Diameter in
inches

2 3/4
2 5/8
2 1/2
2 3/8
2 1/4
2 1/8
2
1 7/8
1 3/4
1 5/8
1 1/2
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1 1/4
1 1/8
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7/8
3/4

NOTE:—
Wire Rope
Data on

Strand dia
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1 1/2
1 3/8
1 1/4
1 1/8
1

Minimu
per square in



Galvanized Steel Bridge Cables

Composed of 7 Strands each having 7, 19 or more Wires
depending upon Cable Diameter

Diameter in inches	Approximate circumference in inches	Approximate weight per foot in pounds	Approximate strength in tons of 2,000 lbs.	Gross metallic area in square inches
$2\frac{3}{4}$	$8\frac{5}{8}$	12.90	310.0	3.59
$2\frac{5}{8}$	$8\frac{1}{4}$	12.10	283.0	3.33
$2\frac{1}{2}$	$7\frac{7}{8}$	11.00	256.0	3.04
$2\frac{3}{8}$	$7\frac{1}{2}$	9.90	232.0	2.75
$2\frac{1}{4}$	$7\frac{1}{8}$	8.91	208.0	2.48
$2\frac{1}{8}$	$6\frac{5}{8}$	7.92	185.0	2.23
2	$6\frac{1}{4}$	7.04	164.0	1.97
$1\frac{7}{8}$	$5\frac{7}{8}$	6.19	144.0	1.72
$1\frac{3}{4}$	$5\frac{1}{2}$	5.39	124.0	1.49
$1\frac{5}{8}$	$5\frac{1}{8}$	4.36	106.0	1.24
$1\frac{1}{2}$	$4\frac{3}{4}$	3.72	90.0	1.06
$1\frac{3}{8}$	$4\frac{3}{8}$	3.12	75.0	0.89
$1\frac{1}{4}$	$3\frac{7}{8}$	2.57	62.0	0.73
$1\frac{1}{8}$	$3\frac{1}{2}$	2.09	54.0	0.59
1	$3\frac{1}{8}$	1.65	42.0	0.47
$\frac{7}{8}$	$2\frac{3}{4}$	1.27	28.5	0.36
$\frac{3}{4}$	$2\frac{3}{8}$	0.96	24.4	0.27

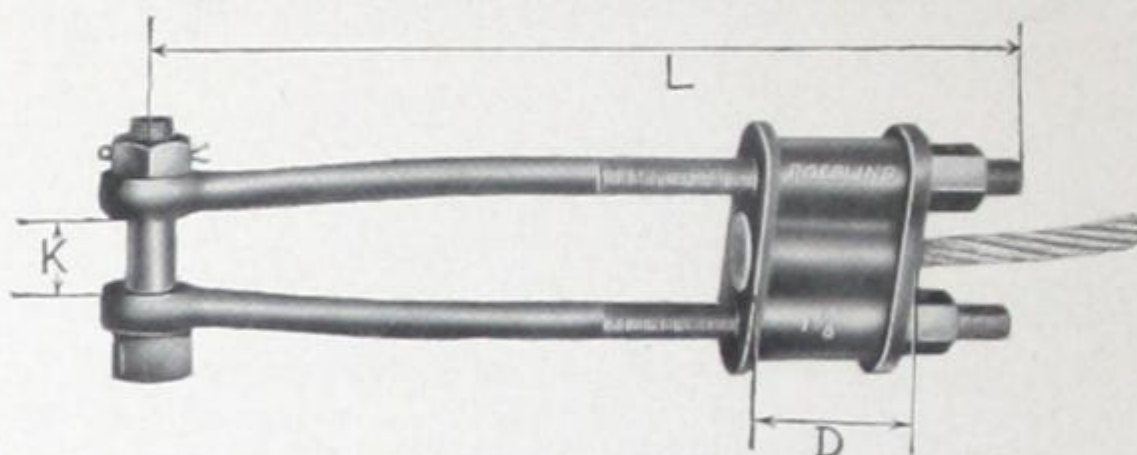
NOTE:—Cables of 1" diameter and larger usually furnished with Independent Wire Rope center.

Data on Bridge Cables up to $4\frac{1}{2}$ " diameter will be furnished upon application.

Galvanized Steel Bridge Strands

Strand diameter, inches	Weight per foot, pounds	Area square inches	Minimum ultimate strength, pounds
$1\frac{1}{2}$	4.70	1.337	270,000
$1\frac{3}{8}$	3.90	1.105	223,000
$1\frac{1}{4}$	3.38	.956	194,000
$1\frac{1}{8}$	2.82	.798	161,000
1	2.01	.569	115,000

Minimum Modulus of Elasticity up to 50% of Ultimate Strength, 24,000,000 pounds per square inch.

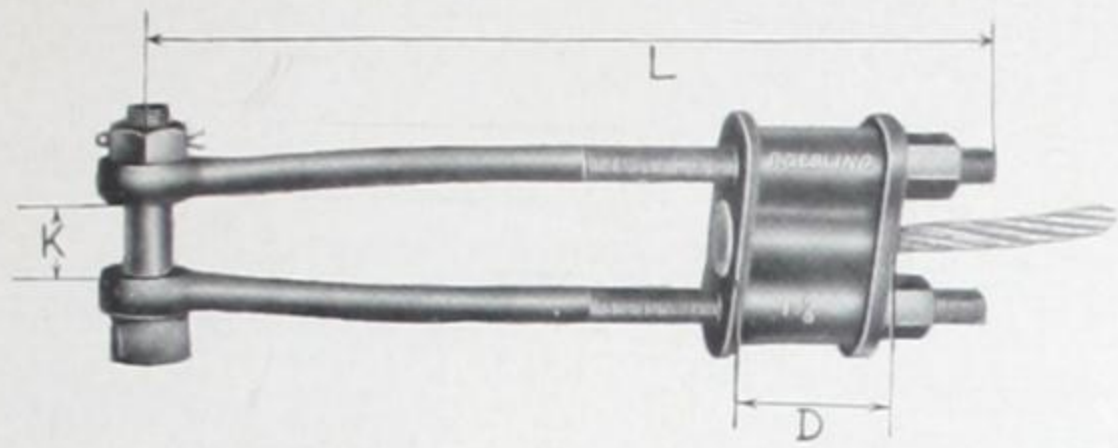


Open Bridge Sockets

For use with "Blue Center" Steel Ropes and Galvanized Bridge Cables
Reg. U. S. Pat. Off.

Diameter of rope in inches	Take up inches	Length of bolts, "L"	Center to center of bolt holes	Depth of socket bowl, "D"	Opening between eyes, "K"	Diameter of pin	Diameter of bolts	Approx. total weight pounds
2 $\frac{3}{4}$	18	62"	14"	14 $\frac{1}{2}$ "	5"	4 $\frac{3}{4}$ "	3 $\frac{1}{2}$ "	990
2 $\frac{1}{2}$	18	60	14	14	4 $\frac{1}{2}$	4 $\frac{1}{2}$	3 $\frac{1}{4}$	860
2 $\frac{1}{4}$	18	56	11 $\frac{7}{8}$	12 $\frac{1}{2}$	4 $\frac{1}{4}$	4	3	630
2	18	52	10 $\frac{1}{4}$	11 $\frac{1}{8}$	4	3 $\frac{3}{4}$	2 $\frac{3}{4}$	470
1 $\frac{3}{4}$	15	42	8 $\frac{1}{4}$	8 $\frac{1}{2}$	3 $\frac{1}{2}$	3 $\frac{1}{4}$	2 $\frac{1}{2}$	290
1 $\frac{5}{8}$	15	39	7 $\frac{1}{8}$	7 $\frac{1}{2}$	3 $\frac{1}{4}$	3	2 $\frac{1}{4}$	225
1 $\frac{1}{2}$	15	39	7 $\frac{1}{8}$	7 $\frac{1}{2}$	3	2 $\frac{3}{4}$	2 $\frac{1}{4}$	220
1 $\frac{3}{8}$	12	36	6 $\frac{1}{2}$	7	2 $\frac{3}{4}$	2 $\frac{1}{2}$	2	160
1 $\frac{1}{4}$	12	32	6	6 $\frac{1}{2}$	2 $\frac{1}{2}$	2 $\frac{1}{4}$	1 $\frac{3}{4}$	110
1 $\frac{1}{8}$	12	30	5 $\frac{1}{2}$	6	2 $\frac{1}{4}$	2	1 $\frac{5}{8}$	85
1	9	25	5	5 $\frac{1}{4}$	2	1 $\frac{7}{8}$	1 $\frac{3}{8}$	60
$\frac{7}{8}$	9	23	4 $\frac{1}{2}$	4 $\frac{5}{8}$	1 $\frac{3}{4}$	1 $\frac{5}{8}$	1 $\frac{1}{4}$	42
$\frac{3}{4}$	9	21	4	4 $\frac{1}{8}$	1 $\frac{1}{2}$	1 $\frac{1}{2}$	1 $\frac{1}{8}$	32

Prices furnished on application.



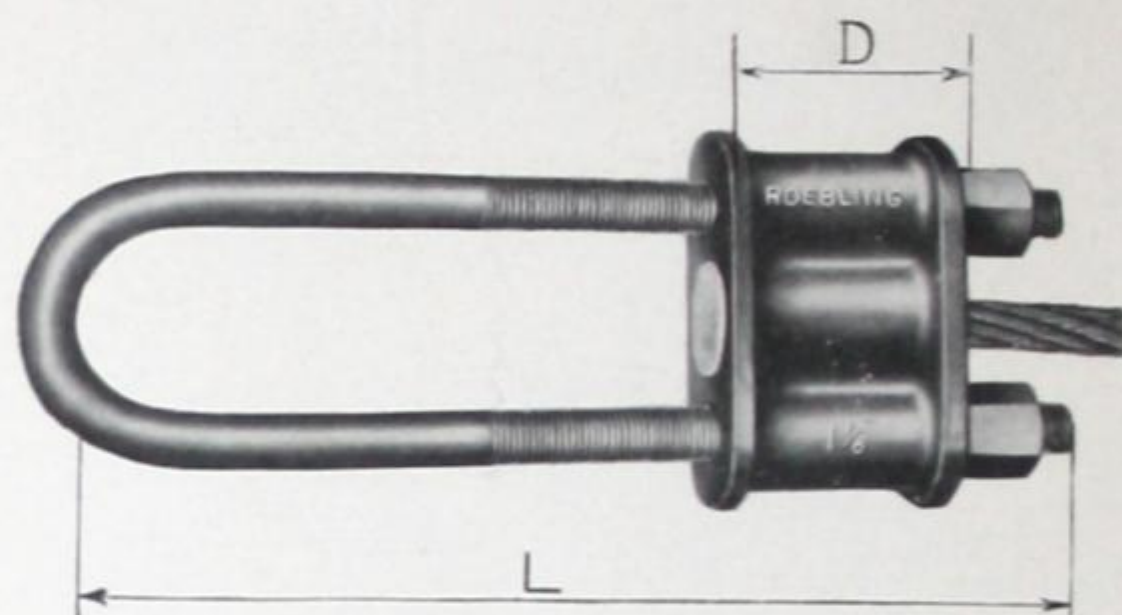
Open Bridge Sockets

For use with Plow Steel and Cast Steel Ropes

Diameter of rope, inches	Take up, inches	Length of bolts "L"	Center to center of bolt holes	Depth of socket bowl "D"	Opening between eyes "K"
2 3/4	18	62"	14"	14 1/2"	4 3/4"
2 1/2	18	60	14	14	4 1/4
2 1/4	18	54	11 7/8	12 1/2	3 3/4
2	18	50	10 1/4	11 1/8	3 1/2
1 3/4	15	42	8 1/4	8 1/2	3 1/4
1 5/8	15	39	7 1/8	7 1/2	3 1/4
1 1/2	15	39	7 1/8	7 1/2	3
1 3/8	12	36	6 1/2	7	2 3/4
1 1/4	12	32	6	6 1/2	2 1/2
1 1/8	12	30	5 1/2	6	2 1/4
1	9	25	5	5 1/4	2
7/8	9	23	4 1/2	4 5/8	1 3/4
3/4	9	21	4	4 1/8	1 1/2

Diameter of rope, inches	Plow Steel Ropes			Cast Steel Ropes		
	Diameter of pin	Diameter of bolts	Approximate weight pounds	Diameter of pin	Diameter of bolts	Approximate weight pounds
2 3/4	4 1/2"	3 1/2"	975	4"	3"	790
2 1/2	4	3	750	3 3/4	2 3/4	650
2 1/4	3 3/4	2 3/4	530	3 1/4	2 1/2	440
2	3 1/4	2 1/2	375	3	2 1/4	330
1 3/4	3	2 1/4	250	2 3/4	2	209
1 5/8	2 3/4	2	185	2 1/2	1 3/4	144
1 1/2	2 1/2	2	175	2 1/4	1 5/8	125
1 3/8	2 1/2	1 3/4	127	2 1/4	1 1/2	105
1 1/4	2 1/4	1 5/8	100	2	1 3/8	80
1 1/8	2	1 3/8	70	1 7/8	1 1/4	57
1	1 3/4	1 1/4	51	1 5/8	1 1/8	45
7/8	1 1/2	1 1/8	37	1 3/8	1	32
3/4	1 3/8	1	27	1 1/4	7/8	22

Prices furnished on application.

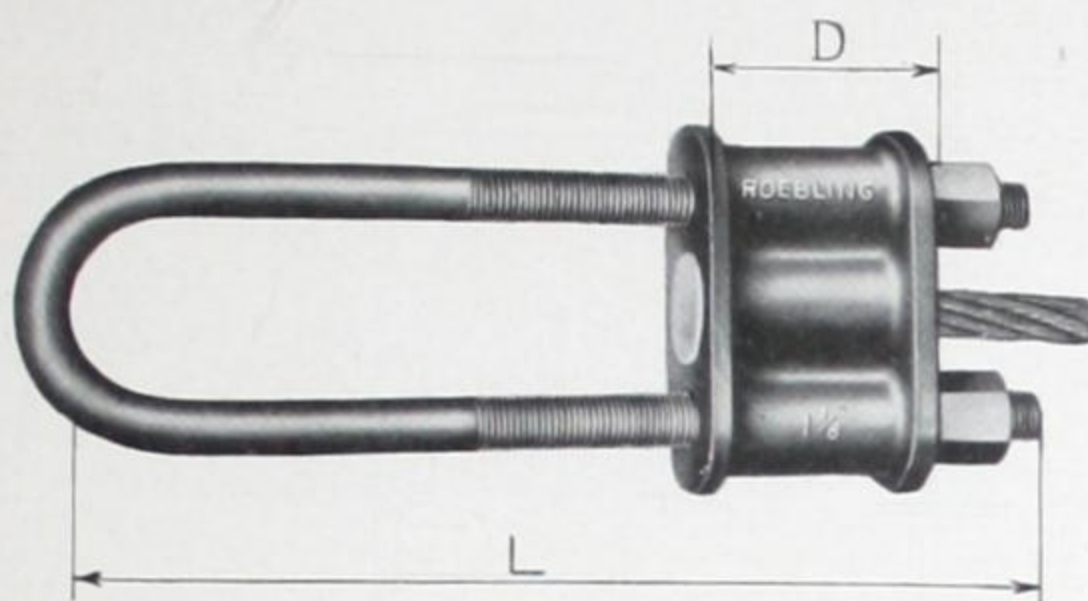


Closed Bridge Sockets

For use with "Blue Center" Steel, Plow Steel and Cast Steel Ropes and
Reg. U. S. Pat. Off.
Galvanized Bridge Cables

Diameter of rope in inches	Take up, inches	Length of "U" bolt "L"	Center to center of bolt holes	Depth of socket bowl, "D"
$2\frac{3}{4}$	18	48"	14"	$14\frac{1}{2}$ "
$2\frac{1}{2}$	18	45	14	14
$2\frac{1}{4}$	18	42	$11\frac{7}{8}$	$12\frac{1}{2}$
2	18	39	$10\frac{1}{4}$	$11\frac{1}{8}$
$1\frac{3}{4}$	15	33	$8\frac{1}{4}$	$8\frac{1}{2}$
$1\frac{5}{8}$	15	30	$7\frac{1}{8}$	$7\frac{1}{2}$
$1\frac{1}{2}$	15	30	$7\frac{1}{8}$	$7\frac{1}{2}$
$1\frac{3}{8}$	12	26	$6\frac{1}{2}$	7
$1\frac{1}{4}$	12	24	6	$6\frac{1}{2}$
$1\frac{1}{8}$	12	22	$5\frac{1}{2}$	6
1	9	18	5	$5\frac{1}{4}$
$\frac{7}{8}$	9	17	$4\frac{1}{2}$	$4\frac{5}{8}$
$\frac{3}{4}$	9	16	4	$4\frac{1}{8}$

Prices furnished on application.



Closed Bridge Sockets

For use with "Blue Center" Steel, Plow Steel and Cast Steel Ropes and
Reg. U. S. Pat. Off.
Galvanized Bridge Cables

Ropes and

Depth of socket
bowl, "D"

Diameter of rope in inches	"Blue Center" Steel Rope and Bridge Cables		Plow Steel Ropes		Cast Steel Ropes	
	Diameter of "U" bolt	Approximate weight pounds	Diameter of "U" bolt	Approximate weight pounds	Diameter of "U" bolt	Approximate weight pounds
14½"						
14	2¾	3½"	3½"	690	3"	590
12½	2½	3¼	3	550	2¾	500
11½	2¼	3	2¾	385	2½	345
	2	2¾	2½	280	2¼	252
8½						
7½	1¾	2½	2¼	175	2	153
7½	1⅝	2¼	2	125	1¾	97
7	1½	2¼	2	125	1⅝	90
	1⅜	2	1¾	81	1½	70
6½						
6	1¼	1¾	1⅝	65	1⅜	56
5¼	1⅛	1⅝	1⅜	46	1¼	42
4⅝	1	1⅜	1¼	34	1⅛	31
4½	⅞	1¼	1⅛	24	1	22
	¾	1⅛	1	18	⅞	16

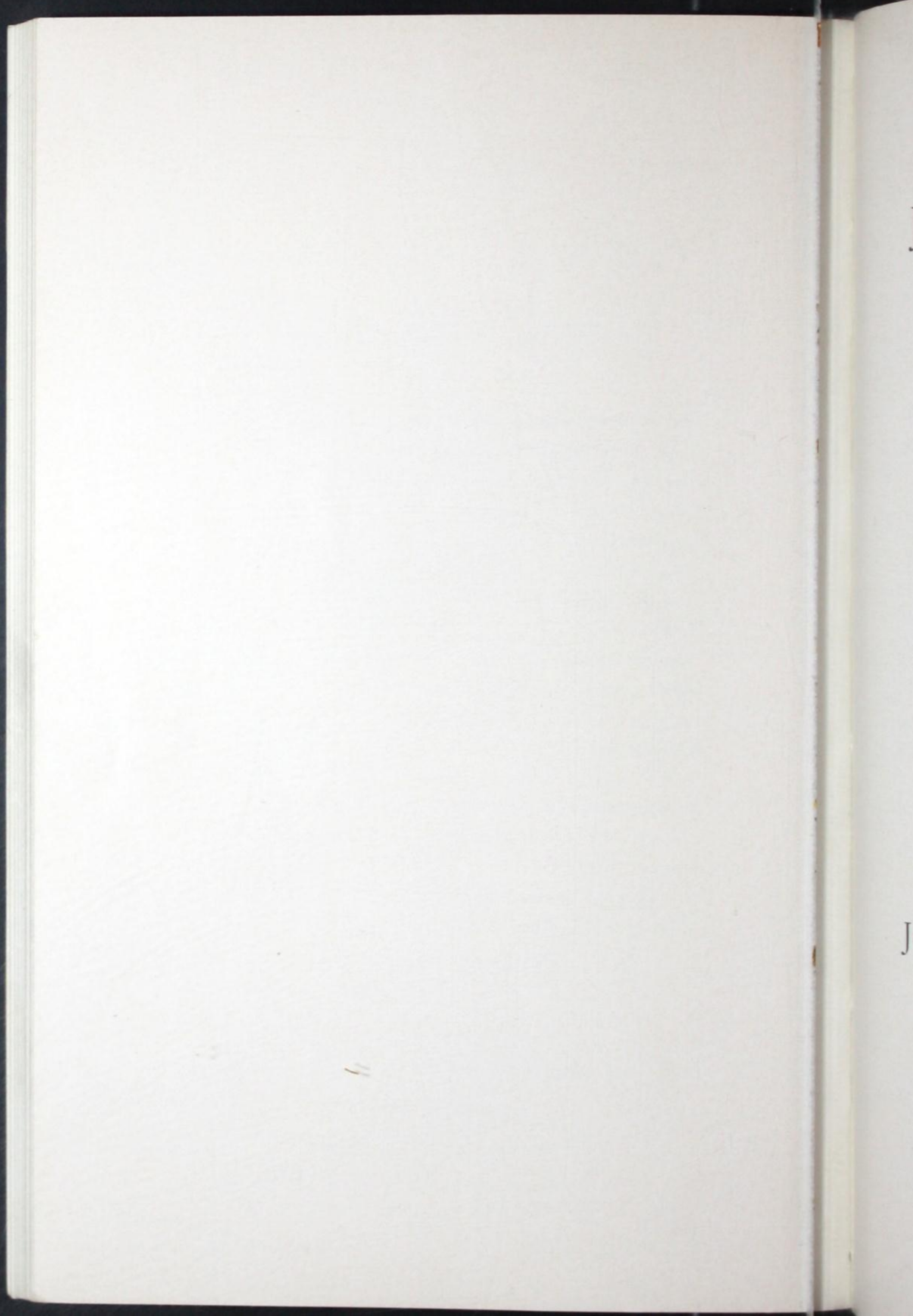
Prices furnished on application.



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Roebling Wire Rope Sockets
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